

EXERCISES IN ELECTRICAL ENGINEERING

MATHER & HOWE

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EXERCISES IN ELECTRIC
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Exercises in Electrical Engineering

FOR THE USE OF SECOND-YEAR STUDENTS
IN UNIVERSITIES AND TECHNICAL COLLEGES

BY

T. MATHER, WH. SCH., F.R.S., M.I.E.E.

PROFESSOR OF ELECTRICAL ENGINEERING, CENTRAL TECHNICAL COLLEGE

AND

G. W. O. HOWE, WH. SCH., M.Sc., M.I.E.E.

ASSISTANT-PROFESSOR OF ELECTRICAL ENGINEERING, CENTRAL TECHNICAL COLLEGE
SOUTH KENSINGTON



LONDON

EDWARD ARNOLD

41 & 43 MADDOX STREET, BOND STREET, W.

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TO THE
MEMBERS OF THE

PREFACE

A CONSIDERABLE time having elapsed since the publication of a collection of exercises in electrical engineering, the present moment seems opportune for carrying out a plan which has often been suggested, namely, the collection and publication of a selection of the questions set in recent years in the second-year exercise classes and examinations at the Central Technical College. The questions have been revised where necessary, and classified and graded for publication. It is hoped that they may be found useful in the second-year work of other colleges and institutions of university rank.

To get a thorough grasp of the matter dealt with in lectures, it is absolutely essential that students work out for themselves numerous exercises on the subjects under consideration. If exercise classes are held, these should not be of the nature of examinations, but the students should be encouraged to discuss the questions with the lecturer and even with each other.

From a perusal of the exercises it will be seen that their object is to cultivate familiarity with, and an exact working knowledge of, fundamental principles rather than a superficial knowledge of modern electrical practice.

Answers to the numerical examples have been added at the end of the book so that the students may have a check on their work. It is desirable, of course, for the pupils' own

benefit that a question should be worked out carefully before the answer given in the book is consulted.

Our best thanks are due and are hereby tendered to Mr. F. E. Meade and Mr. J. C. Hutton, of the Central Technical College, for much assistance in copying and working out many of the questions.

T. MATHER.

G. W. O. HOWE.

SOUTH KENSINGTON,
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EXERCISES IN ELECTRICAL ENGINEERING

I.—UNITS ; OHM'S LAW ; JOULE'S LAW ; TEMPERATURE COEFFICIENT

1. If a current of 1 ampere deposits $4\frac{1}{40}$ grammes of silver in one hour, find the amount of silver deposited by a million coulombs.

2. If a current of 5 amperes be taken from 110 volt mains, find the quantity of electricity passing per hour.

3. If the agreement with an Electric Supply Company is to the effect that 4*d.* shall be charged per Board of Trade unit, how can the amount of the bill be ascertained from readings of a coulomb meter ?

4. What exactly is meant by a “ quantity of electricity ” ? Compare the industrial value of a quantity of electricity at the potential of the earth with a quantity of coal-gas at atmospheric pressure.

5. Calculate the relation between the British Thermal Unit and the Board of Trade Unit.

6. What will be the cost of heating a quart of water to the boiling-point in an electrical kettle, if the efficiency be 80 per cent. and the cost of electrical energy 2*d.* per B.O.T. unit ?

2. EXERCISES IN ELECTRICAL ENGINEERING

7. Calculate the cost of heating 10 lbs. of water from 60° F. to the boiling-point by means of electrical energy at one penny per unit. Assume that the apparatus has an efficiency of 90 per cent. (Mechanical equivalent of heat = 778 foot-pounds per pound degree Fahrenheit.)

8. The average for 1905 in one of the largest and most economical power stations in the world was 2.38 lbs. of coal per K.W.-hour generated. The average calorific value of the coal was 12,368 B.Th.U. per lb. Find the overall efficiency, and state approximately how the losses would be distributed between the boilers, engines, and dynamos.

9. If a suction-gas plant on full load test burns $\frac{3}{4}$ lb. of anthracite (15,000 B.Th.U. per lb.) per B.H.P.-hour, what is the overall efficiency of the producer and engine?

10. If the British Thermal Unit is equivalent to 778 ft.-lbs., find the relation between the horse-power-hour and the calorie. What amount of coal must be burnt in a modern power station to supply 10 carbon filament lamps of 16 c.p. for four hours? Assume what you consider suitable efficiencies.

11. Describe any method of converting thermal energy directly into electrical energy. Why has the method described not been generally adopted on a large scale?

12. Calculate the relation between the B.O.T. unit, the horse-power-hour, and the foot-pound.

13. If a reservoir 150 feet above the turbine house contains 100,000 tons of water, what is the value of the energy thus stored at one penny per Board of Trade unit?

14. Find the cost of hoisting 100 tons 80 feet by means of an electric motor, if the price of energy is $1\frac{1}{2}$ d. per unit. The combined efficiency of motor and gearing may be taken as 60 per cent.

15. Find the brake horse-power of a motor to lift 4 tons

a height of 500 feet in 2 minutes, if the efficiency of the motor is 90 per cent. and that of the gear 80 per cent. What will the operation cost if the price of energy is $2d.$ per unit?

16. A centrifugal pump lifts 85 gallons of water per minute against a head of 35 feet. The motor takes a current of 10 amperes at 200 volts. Find the overall efficiency of the set.

17. A crane is required to hoist 10 cwts. 50 feet in 15 seconds. The efficiency of the hoisting gear, excluding the motor, is 70 per cent., while that of the motor alone is 85 per cent. Find (a) the B.H.P. of the motor, and (b) the cost of hoisting, per ton, if the price of energy is one penny per unit.

18. What must be the brake horse-power of a motor to hoist a ton 200 feet in one minute? Find the cost of each operation if the price of electrical energy is one penny per unit. Assume suitable efficiencies.

19. Find the cost of hoisting 4 tons 100 feet in 5 minutes by means of an electric crane, if energy cost one penny per kilowatt-hour. Efficiency of motor 90 per cent., efficiency of gear 80 per cent.

20. Give definitions of a watt, a joule, and a Board of Trade unit. What instruments would you employ to measure (a) the power supplied to an electric circuit, (b) the energy supplied to an electric circuit?

21. If 4 yards 6 inches of No. 20 copper wire (diam. = $0.036''$) has a resistance of $\frac{1}{10}$ ohm, what is the resistance between the opposite faces of a cube of copper of 1 cm. edge?

22. Find the specific resistance of mercury from the practical definition of the ohm.

23. Find the resistance between the brushes of a two-pole

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armature wound with 1000 feet of wire 2 mm. diameter. The specific resistance of warm copper may be taken as 2×10^{-6} ohms per cm. cube.

24. Three resistance coils are connected in parallel. A P.D. of 10 volts sends a total current of 5 amperes through them. If two of them are known to be 5 ohm coils, what is the resistance of the third?

25. A cylindrical coil has an inner diameter of 2 cms., an outer diameter of 3 cms., and a length of 4 cms. : find its resistance if a P.D. of 2 volts is necessary to produce 300 ampere-turns. (Assume that one-half of the available space is occupied by copper, the remainder by insulation and air spaces, and that the specific resistance of copper is 1.7 microhms per cm. cube.)

26. The shunt dynamo in Fig. 1 produces a P.D. of 105 volts between the brushes. The main conductors have a resistance throughout of $\frac{1}{500}$ ohm per yard, and at *ab*, *cd*, and *ef* there are 10 sixteen candle-power lamps in parallel, each

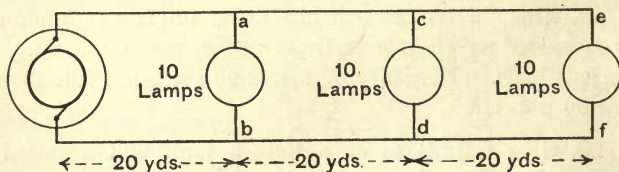


FIG. 1.

of which absorbs 60 watts when the P.D. between its terminals is 100 volts. Calculate what is the actual P.D. between the terminals of each of the three sets of lamps respectively.

27. A dynamo having an E.M.F. of 250 volts and an armature resistance of 0.25 ohm is charging a battery of accumulators with a back E.M.F. of 220 volts and a resistance of 0.1 ohm through a regulating resistance of 0.25 ohm. Find the P.D. between the various points of the circuit, and also

the power wasted and usefully employed in both dynamo and battery.

28. Two coils are connected in parallel and a P.D. of 100 volts applied to the terminals. The total current taken is 15 amperes, and the power dissipated in one of the coils is 500 watts. What is the resistance of the other coil?

29. Compare the power, and also the energy, given to a circuit in the following cases :—

- (a) A continuous current of 12 amperes flowing at a P.D. of 100 volts for $1\frac{1}{2}$ hours ;
- (b) A continuous current of 8 amperes flowing at a P.D. of 200 volts for $\frac{3}{4}$ hour.

30. Power is electrically transmitted by means of a given current generator of fixed E.M.F. and resistance, through a pair of given conductors to a coil of wire used for warming water. Calculate (1) what should be the resistance of this coil so that the water may be heated most rapidly ; and (2) what should be the resistance of the coil so that $\frac{3}{4}$ of the total energy developed by the generator may appear as heat in the water.

31. The resistance of the field winding of a dynamo is 50 ohms at 15° C. After running for several hours, the current in the field winding is found to be 2 amperes when the P.D. between its terminals is 114 volts. What is the average temperature throughout the winding ?

32. A coil of copper wire having a resistance, when cold, of 50 ohms, is subjected to two distinct heating tests ; in the first test a constant P.D. of 100 volts is maintained across it, whereas in the second test the current is maintained constant at 2 amperes. Will the final temperatures differ ? if so, why ?

33. A resistance is required to carry a certain current and to dissipate a certain amount of power without exceeding a

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specified temperature rise. If made of copper, 100 feet would be required with a diameter of $\frac{1}{20}$ ". Find the length and diameter of German silver wire to answer the same purpose, if the conditions as to emissivity and cooling are the same in each case. The specific resistance of G.S. is 15 times that of copper.

II.—MAGNETISM. ELECTROMAGNETS

1. Two bar magnets are placed in line with their north poles facing each other at a distance of 10 cms. If the strength of each pole is 10 units, find the strength of the magnetic field at a point midway between them.

(1) 2. Three bar magnets are arranged so that their north poles lie on the corners of an equilateral triangle of 6 inches side, while their south poles are so far away that they may be neglected. The strengths of the poles are 100, 200, and 300 units respectively. Find the force acting on the pole of 100 units.

3. Define what is meant by the temporary magnetic induction, the residual magnetic induction, and the coercive force of a piece of iron. Discuss the relative values of these three quantities for soft iron and hard steel.

4. What is meant by magnetomotive force, and how is it related to electromotive force? Write out the equation for the magnetic flux, which corresponds to Ohm's Law for the electric circuit.

5. What analogies exist between a magnetic and an electric circuit? How would you decide on the smallest cross-section to give to any part of the magnetic circuit? Discuss the plan used in some of the early dynamos of making the electromagnet very long compared with the diameter of the armature. If this be wrong, then why is a horse-shoe permanent magnet still made long compared with the dimensions of the armature?

6. What is meant by the strength of a magnetic field, the value of the magnetising force, and the magnitude of the induction in a piece of iron ?

7. Explain exactly what you understand by the symbols B , H , and μ , and explain the relations between them.

8. Show the analogy, and also the important differences, between the electric circuit and the magnetic circuit. What is the electric equivalent of H ?

9. Explain precisely what is meant by the magnetising force H . What is the analogous magnitude in the electric circuit ?

10. The coil of a tangent galvanometer contains 10 turns and has a diameter of 20 cms. The current passing through it is 1 ampere. Find the strength of the magnetic field at a point on the axis of the coil, 10 cms. from the plane of the coil.

11. Deduce from first principles an expression for the strength of field at the centre of a long solenoid.

12. A glass tube 1" external diameter and 1 yard long is wound uniformly from end to end with 900 turns of insulated copper wire, 0.9 mm. diameter bare and 1.0 mm. diameter over the insulation. Find the strength of the magnetic field inside the solenoid when a P.D. of two volts is applied to its terminals.

13. A straight piece of wrought-iron wire 1 metre long and 1 mm. diameter is wound uniformly from end to end with 1000 turns of wire. Find the strength of the poles when a current of 1 ampere is passed through the winding. (See Fig. 2.)

14. The following data apply to a lecture demonstration of the magnetometer method of testing the permeability of a specimen of iron wire. Length of solenoid and wire 1 metre, turns on solenoid 1400, diameter of iron wire 1.2 mm., distance from lower pole to needle 8 cms. (at right angles to meridian)

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the upper pole is vertically above the needle; distance from mirror to scale, 17 feet; deflection obtained with 2 amperes,

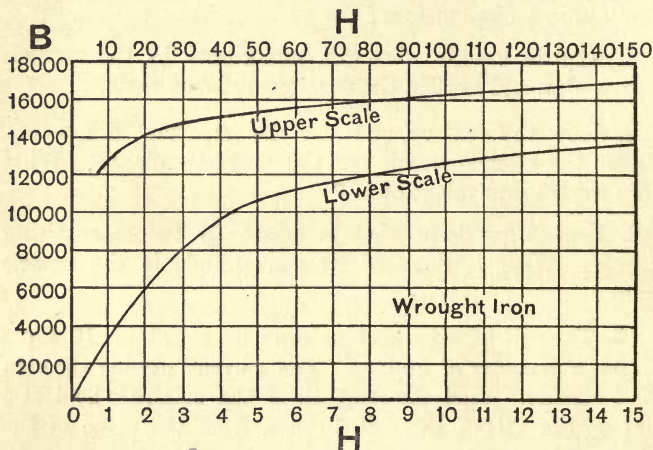


FIG. 2.

80 inches; horizontal component of the earth's field, 0.18. Find the permeability of the specimen.

15. A glass tube 1" diameter is bent round to form a ring of 1 foot mean diameter. How many ampere-turns must be wound on the ring to produce a total flux of 1000 lines through the tube?

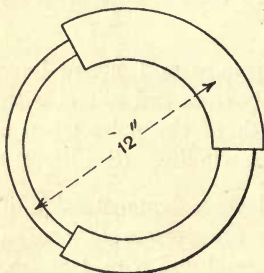


FIG. 3.

16. Find the ampere-turns required to maintain a flux of 10,000 lines round the wrought-iron ring (Fig. 3), the mean diameter of which is a foot, and which is made up of three equal lengths of round bar of 1 cm., 2 cms. and 3 cms. diameter respectively. (See Fig. 2.)

17. A ring with a mean diameter of 6 inches is made from $\frac{1}{4}$ " diameter round iron. It is wound with 100 turns of insulated

wire. Find the current necessary to produce a total flux in the ring of 5000 lines. The permeability μ may be taken as 1000.

18. An iron ring with a mean circumference of 100 cms. and a cross-section of 10 sq. cms. is wound with 400 turns of wire carrying a current of 2 amperes, and the flux is found to be 100,000 lines. Determine the permeability of the specimen of iron.

19. How many ampere-turns are necessary to produce a flux density of 13,500 lines per sq. cm., in a soft iron ring 15" mean diameter, made of round iron 1.5" diameter, if the permeability at this flux density be 900 ?

20. An iron ring of 25 cms. mean diameter and 10 sq. cms. cross-sectional area has an air-gap of 1 mm. It is wound with 500 turns of wire carrying a current of 8 amperes. If the permeability be equal to 600, determine the magnetomotive force of the coil, the reluctance of the ring, and the flux density in the air gap.

21. Given the following particulars of a direct current generator, find the ampere-turns which must be wound round the field to drive the required flux through the air-gap.

Bipolar machine to give 200 volts at 2000 r.p.m. Length of armature, 32 cms. Length of single air-gap 1.8 cms. Portion of circumference of armature covered by pole-faces, 60 cms. Number of conductors round armature, 200.

22. An iron anchor ring of 6" mean diameter is made of round rod of 0.5" diameter, and is wound with 250 turns of insulated wire. If it be sawn through across a diameter, find approximately the force required to pull the two semicircular halves apart when the coil is carrying a current of 1 ampere. The permeability of the iron for various values of the flux density per sq. cm. is as follows :—

$$B = 8000 ; 10,000 ; 12,000$$

$$\mu = 2580 ; 2270 ; 1540$$

23. Calculate the ampere-turns required for the cast-steel

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magnet sketched in Fig. 4. The air-gap density is to be 50,000 lines per sq. inch, and the coils are to be placed on the polar projections N. and S. The section of each polar

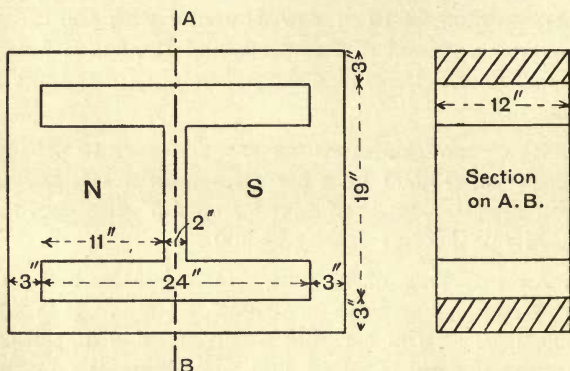


FIG. 4.

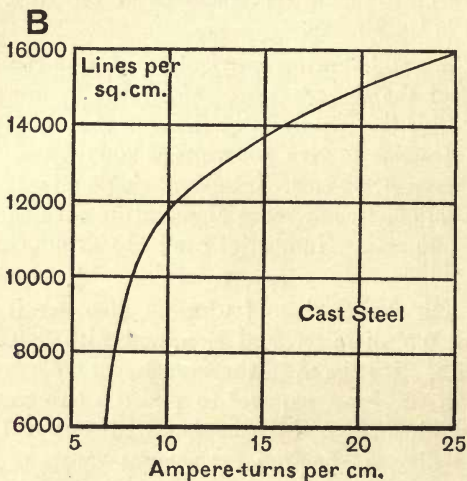


FIG. 5.

projection is 12 inches square. Leakage can be neglected. Show the direction of the current in the windings. (See Fig. 5.)

24. What materials are used in the various parts of the

magnetic circuit of a good modern dynamo? Give reasons for their adoption in each case.

25. How would you find the permeability of a sample of steel for making dynamo or motor field castings? Draw a curve showing approximately to scale the variation of permeability with induction which you would expect in a good sample.

26. How would you determine the magnetic qualities of a specimen sheet of soft iron?

27. Explain how you would test a sample of sheet iron as to its suitability for armature construction. Indicate approximately the results you would expect.

28. An iron ring has a cross-section of 0.335 sq. cm. and a mean diameter of 10 cms. It is wound with a magnetising winding of 320 turns and a secondary winding of 220 turns. On reversing the current of 10 amperes the ballistic galvanometer gave a reading of 272; a Hibbert standard with 10 turns and a flux of 25,200 lines gave a reading of 102. Find the permeability of the ring.

29. Explain how you could determine the permeability of a bar of iron with the help of a spring balance.

30. A horse-shoe permanent magnet is fixed in a stand, so that it can lift the keeper off the table. If the keeper is taken off and replaced on the table, the magnet will lift it again the moment it is released. This can be repeated indefinitely. Explain how it is that the magnet can do this work and yet remain unchanged.

31. What is the approximate amount of energy stored in the

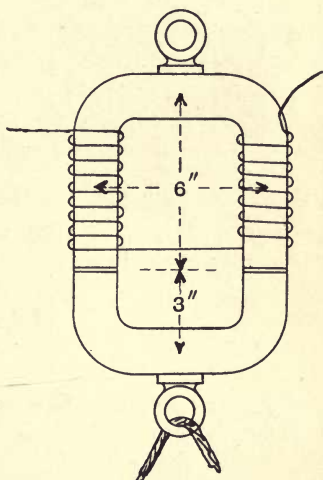


FIG. 6.

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magnetic field of a solenoid 1 foot long and 1" diameter, wound with 300 turns, and carrying a current of 5 amperes ?

32. Prove the formula for the lifting power of an electro-magnet.

33. Fig. 6 shows an electromagnet constructed throughout of wrought-iron bar of 2" diameter. If there are 50 turns on each limb, find the necessary current to support 2 cwt. (See Fig. 2 for B—H curve.)

34. A ring of 6" mean diameter is made of $\frac{1}{2}$ " round wrought iron. If it be split across a diameter, find how many ampere-turns will be necessary to give it a lifting power of 24 lbs.

Given B = 10,000	12,000	15,000
$\mu = 2500$	1800	600

35. (a) Calculate the ampere-turns necessary to produce

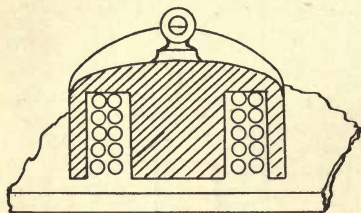


FIG. 7.

a flux of a million lines through the magnetic circuit of the circular lifting magnet shown in section in Fig. 7. The cross-section of iron throughout the magnetic path is 100 sq. cms., the mean length of the magnetic path is 40 cms. Assume an

air gap of 2 mm. between the magnet and the armature. The quality of the iron is such that

when B = 10,000 lines per sq. cm. $\mu = 2500$

„ B = 12,000 „ „ „ $\mu = 1800$

„ B = 15,000 „ „ „ $\mu = 600$

(b) What weight will the above magnet support under these conditions ?

III.—FORCES ON CONDUCTORS. ELECTRO-MAGNETIC INDUCTION

1. A current of 400 amperes is carried by two bare copper wires in parallel. The wires have a diameter of $\frac{1}{4}$ ", and are supported side by side, the distance between centres being $\frac{1}{2}$ ". Find the force on each wire per foot of length.

2. If the connections between a dynamo and an electrolytic vat taking 1000 amperes consist of two parallel copper bars supported on insulators 6 inches apart, calculate the mechanical force between the conductors per foot.

3. The moving coil of a galvanometer has 60 turns, a width of 2 cms. and a depth of 3 cms. It hangs in the plane of a magnetic field of 500 C.G.S. units. Find the turning moment acting upon the coil when it is carrying a current of 1 milliampere.

4. A 4-pole cylindrical armature 40 cms. diameter has 944 wires on its periphery. The axial length is 24 cms. Two-thirds of all the wires are under the poles, and are so connected that they all exert torque in the same direction. If the strength of the field between the poles and armature is 7000 units, find the torque exerted on the armature in inch-lbs. when each wire carries a current of 10 amperes.

5. If the coil shown in Fig. 8 is free to move to the right

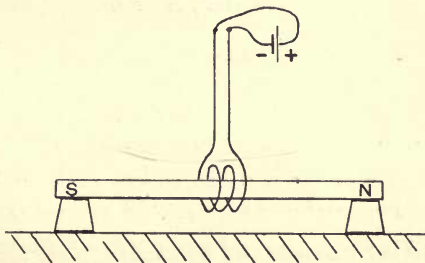


FIG. 8.

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or to the left, consider whether it is in equilibrium or not. If it is, is the equilibrium stable or unstable ; if not, in which direction will it move ?

ELECTROMAGNETIC INDUCTION

6. A circle of wire is rotated in a uniform field about a diameter lying along a line of force. Describe exactly what happens.

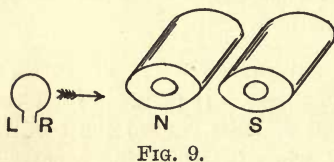


FIG. 9.

7. A coil is moved past magnet poles in the direction indicated in Fig. 9. State the direction of the E.M.F. induced in the coil in various positions along its path.

8. A coil is placed in a uniform magnetic field with its plane perpendicular to the lines of force. It is (a) moved vertically in its own plane, (b) moved in the direction of the field, (c) rotated about a vertical axis, (d) rotated about an axis parallel to the lines of force.

In which case or cases is an E.M.F. induced, and why ?

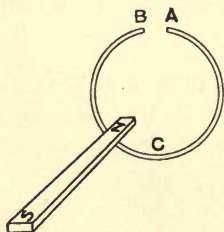


FIG. 10.

9. The north pole of a magnet is moved towards the open loop AB, as shown in Fig. 10. Which is at the higher potential, A or B ?

The resistance of the loop AB is 1 ohm, and the ends are joined to form a continuous ring. As the north pole is moved towards it there is a momentary current of $\frac{1}{20}$ ampere. What is the P.D. at this moment between the joint AB and the opposite point C ?

10. Two bar magnets and a rod of iron are placed as shown in the two Figs. 11 (a) and 11 (b), and a short-circuited coil

of wire is moved from right to left in each case. Indicate for each case the direction of the current induced in the coil when

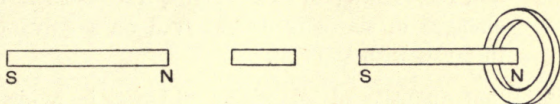


FIG. 11a.

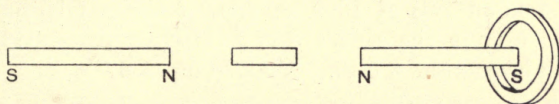


FIG. 11b.

it is at various points of its path, and mark the places, if any, where the current in the coil reverses.

11. (a) A coil C is moved from a distance towards a magnet M, then onwards over the magnet—the magnet being then inside the coil—and finally is moved off to the left. At what point will the direction of the E.M.F. induced in the coil reverse? (See Fig. 12a.)

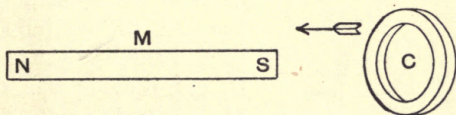


FIG. 12a.

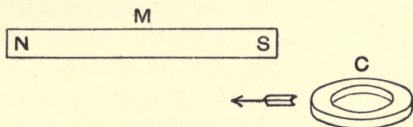


FIG. 12b.

- (b) Consider the same question when the coil is held horizontally and is moved under the magnet from right to left as shown in Fig. 12b.

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- (c) If, in the first case, the coil be brought up nearly to the south pole, then turned through 180° , *i.e.* reversed, and removed again to the right, trace out the various changes in the current observed on a galvanometer in series with the coil.

12. What quantity of electricity will pass in a circuit of 20 ohms resistance containing a horizontal coil of 100 turns with a mean area of 1000 sq. cms. if the coil be suddenly turned over in the earth's field? Horizontal component of earth's magnetism = 0.18. Angle of dip = 67° .

13. A coil is in such a position that 1000 lines of force pass through it. It is then moved into such a position that no lines of force pass through it. If the coil has 100 turns and a resistance of 10 ohms, what quantity of electricity will flow round the coil if the time taken for the change of position is (a) 1 second, (b) 10 seconds, and (c) 100 seconds? What conclusion can you draw from your answer?

14. C is a stationary coil of wire carrying a steady current, as shown by the arrow (Fig. 13), and D is a disc rotating about an axis which is also the axis of the coil. If there are sliding

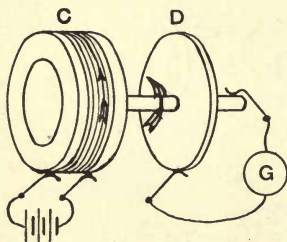


FIG. 13.

contacts at the axis and edge of the disc, will an induced current be sent through the galvanometer G, and, if so, in which direction? If now the disc is kept at rest and the coil be rotated about its axis, sliding contacts being used to carry the current into and out of the rotating coil, consider carefully whether there will be any

difference in the induced current through the galvanometer G, from that obtained in the previous case.

15. Find the change in magnetic density through a search coil with 10 turns, 5 sq. cms. area, 1 ohm resistance, which gives a deflection of 160 divisions on a ballistic galvanometer.

III.—ELECTROMAGNETIC INDUCTION 17

Resistance of galvanometer and leads, 4 ohms. Sensibility of galvanometer, 1 division per microcoulomb.

16. A circular coil of 100 turns of wire having a mean diameter of 30 cms. is rotated about a vertical diameter as an axis at a speed of 16 revolutions per second. Calculate the value of the instantaneous E.M.F. induced in the coil, (1) when it is at right-angles to, (2) when it is inclined at 30° to, (3) when it coincides with, the magnetic meridian. The horizontal component of the earth's magnetic field may be taken as 0.18.

17. A coil of 20 turns with a mean area of 5 sq. cms. and 2 ohms resistance gives a throw of 100 divisions on a ballistic galvanometer on being turned through 180° . The resistance of the galvanometer and leads is 4 ohms. The galvanometer gives a throw of 1 division per microcoulomb. What is the strength of the field in which the coil is placed?

18. A search coil 5 cms. in diameter is wound with No. 40 wire, and is used with a field tester whose sensibility is 1 division per 10 microcoulombs and whose resistance is 20 ohms. Find the number of turns required on the search coil in order that the density per sq. cm. of the field in which the search coil is reversed may be ten times the reading. (2.25 feet of No. 40 wire has a resistance of 1 ohm.)

19. When a continuous P.D. of 150 volts was applied to the field circuit of the Bruce Peebles dynamo, the resistance of which is 30 ohms, the current rose to 60 per cent. of its maximum value in 1.25 seconds. If the bobbins had been wound with wire of half the diameter (in the same space) and a P.D. of 600 volts were applied, what time would be necessary for the current to rise to the same fraction of its ultimate value?

20. Indicate the general shape of the curve showing the growth of current following the application of a steady P.D. to an inductive circuit. What shape will the curve assume—

18 EXERCISES IN ELECTRICAL ENGINEERING

- (1) If the resistance is very large compared with the inductance?
- (2) If the inductance is very large compared with the resistance?

21. Explain exactly what happens when a copper disc is rotated between the poles of a magnet, as in the Thomson energy meter.

22. Explain with the aid of sketches what happens when a large iron disc is rotated so as to cut through the narrow gap between the poles of a horseshoe magnet.

23. Is there any objection to breaking the field circuit of a large shunt dynamo? If so, why?

24. What precautions would you adopt when breaking a very inductive circuit? Explain exactly why such precautions are necessary.

25. Explain why the spark on breaking the circuit of an electromagnet is greater than that on breaking a non-inductive circuit carrying the same current.

26. A circuit is made up of a battery, a solenoid, and a switch. On opening the switch, a flash is seen. Why is this? Will there be any difference in the flash on breaking circuit if (a) a solid core of soft iron, (b) a core of soft iron wires, (c) a core of previously non-magnetised steel be placed in the solenoid?

IV.—INSTRUMENTS

1. Enumerate the various types of ammeters with which you are acquainted, and compare their relative advantages and disadvantages. Give a detailed description of any one ammeter.

2. Describe briefly, with sketches, the various types of instruments suitable for measuring alternating currents.

3. A milli-ammeter reading up to 500 milli-amperes has a resistance of 0.1 ohm. How could this instrument be adapted to read (a) voltages up to 200, and (b) currents up to 20 amperes?

4. A moving coil instrument has a resistance of 100 ohms, and gives a full scale deflection with a P.D. of 3 volts. Explain how you could use the instrument for measuring (1) pressures up to 120 volts; (2) currents up to 20 amperes.

5. Describe the principle and construction of a moving coil ammeter and discuss its advantages and disadvantages as compared with an ammeter of the hot wire type.

6. A wattmeter is employed to measure the power given to the apparatus A. Consider the errors that would be introduced by joining up the wattmeter as illustrated in Fig. 14

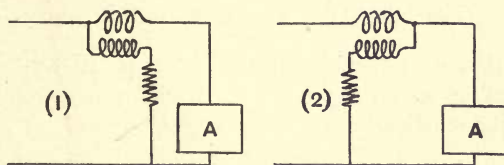


FIG. 14.

(1) and (2) respectively, and determine which way would give the least error. Think out a method of constructing a wattmeter so that it may be free from the errors introduced by either method (1) or (2).

7. Describe the principle and construction of a wattmeter.

8. Explain why a voltmeter should have as high a resistance as is practicable. A voltmeter reading from 0 to 3 volts has a resistance of 300 ohms. How could this instrument be adapted to read from 0 to 300 volts?

20 EXERCISES IN ELECTRICAL ENGINEERING

9. Show how to construct a C.C. voltmeter which, when connected to the mains in the generating station, will indicate the P.D. at the far end of a feeder.

10. Describe with sketches the construction of an electrostatic voltmeter. An electrostatic voltmeter adapted for measuring the P.D. between two mains of about 2000 volts has one of its terminals connected with one main, while the other terminal is by accident left insulated. Consider whether the voltmeter will indicate any P.D. If so, of what value?

11. An electrostatic and an electromagnetic voltmeter are used to measure the P.D. between two direct current mains. Compare the effects on the readings of these two instruments of putting in a resistance between the instrument and the main.

12. Illustrate with sketches some form of coulomb-meter and mention exactly under what conditions such an instrument can be used to measure the energy given to an electric circuit in a given time, and under what conditions it cannot.

13. How does the construction of a quantity-meter differ from that of an energy-meter? Under what circumstances can one be practically used instead of the other?

14. What is a coulomb- or quantity-meter? What are the principles used in the different types of coulomb-meters?

15. Explain how the Elihu Thomson energy-meter records B.O.T. units.

16. If a supply-meter of the motor type has the armature and brake in the same magnetic field, consider how the rate will be altered by a weakening of the field.

17. Define a coulomb, a kilowatt, and a Board of Trade unit. Describe with sketches three instruments such as are commercially employed for measuring electrical quantities in these three units respectively.

18. Why is it desirable to know the maximum current taken during each quarter by each building that is supplied with electrical energy in order that the amount of the charge to be made may be estimated? Give an example of this method of charging.

19. Describe with sketches the construction of some form of maximum demand indicator, and consider whether a Thomson meter could be used both to measure the energy and the maximum demand if the permanent magnets instead of being fixed were arranged so as to be capable of motion.

20. What will be the effect on the sensibility of a moving coil ballistic instrument if the permanent magnet grows weaker? In some instruments a small piece of iron is fixed to the moving coil, and serves to counteract the first effect. How is this?

21. Prove that the swing of a moving-coil ballistic galvanometer is approximately proportional to the quantity of electricity passed through it. Is this true of the moving needle galvanometer? If not, why not?

V.—DYNAMOS AND MOTORS: WINDINGS, CONNECTIONS, AND DIRECTION OF ROTATION

1. The iron ring of a bipolar Gramme armature has an external diameter of 12", internal diameter of 9", and an axial length of 12". It is wound with 1000 turns of 2 mm. copper wire. What is the approximate resistance between the brushes?

2. Compare the advantages and disadvantages of drum and ring windings for armatures.

3. What happens if the armature of a dynamo is rotated in the wrong direction?

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4. The armature of a certain series dynamo is normally rotated clockwise when looked at from the commutator end. What will happen if it be driven counter-clockwise without any other change being made ?

5. Copy the accompanying diagram (Fig. 15). Can it represent a dynamo turning in a clockwise direction ? If so,

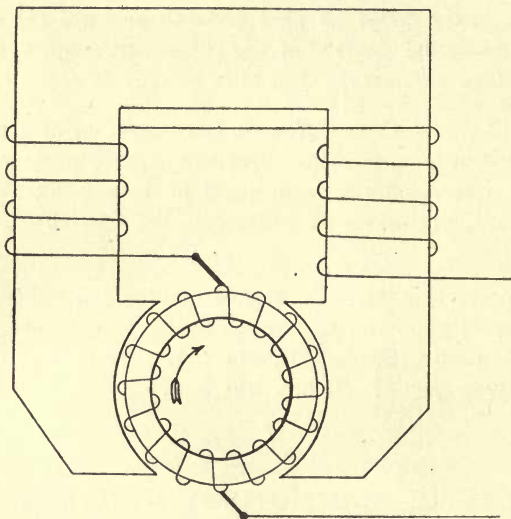


FIG. 15.

indicate the polarity and the directions of both armature and field currents.

6. Make a sketch of a long-shunt compound-wound dynamo and show clearly the direction of the current in every part when the machine is running on load.

7. Copy Fig. 16, which represents a compound-wound dynamo. Put in all the necessary connections and show the directions of the currents in the armature and field coils, the direction of rotation of the armature, the position of

the brushes, the north and south poles of the field magnet, and the positive and negative terminals of the dynamo.

8. What is the exact function of a commutator? Consider whether it is possible by using a commutator to generate a current always in the same direction in a coil of wire by moving it in a magnetic field.

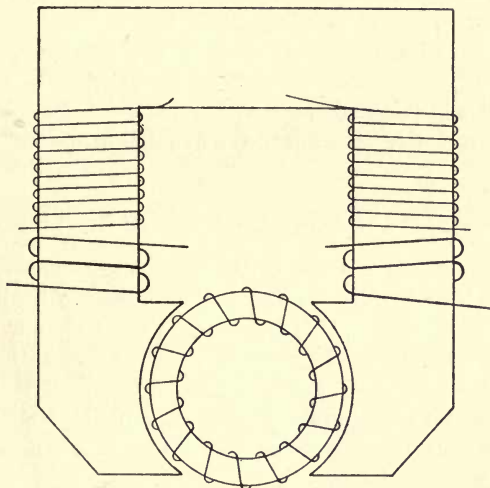


FIG. 16.

9. Draw a diagram of a bipolar Gramme ring motor and show the polarity of the field magnets, the polarity of the brushes, the direction of the current in the armature and the direction of rotation.

10. If we reverse the current through a series motor, do we thereby reverse the direction of rotation? Give reasons.

11. The current passing through a shunt motor is reversed. What effect will be produced on the direction of rotation of the motor, and why?

12. Show by means of sketches how to reverse the direction

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of rotation of a magneto-motor, a series motor, and a shunt motor, respectively, from a distance.

13. A machine has two windings on the armature, each winding being provided with a separate commutator and pair of brushes. One of the windings in combination with the field magnet is employed as a high P.D. motor to revolve the armature, while the other armature winding is used to generate a large current for lighting glow lamps. Make a sketch showing the direction of rotation of the armature, and the direction of the current in each armature winding, and consider what will be the demagnetizing action of the armature as compared with that in an ordinary dynamo or motor.

VI.—E.M.F. INDUCED IN ARMATURE

1. One of the coils of a Gramme ring armature is disconnected from the commutator but connected by flexible leads to a galvanometer. On reversing the field current the maximum galvanometer swing is obtained when the coil is halfway between two poles, whereas if the field is kept constant, and the armature turned suddenly through a small angle, the galvanometer swing is a minimum when the coil is in this position. Explain this.

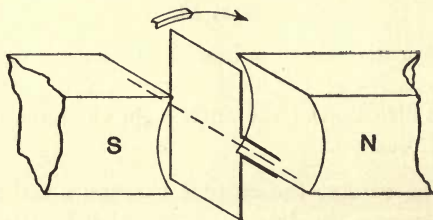


FIG. 17.

2. A rectangle is rotated at uniform speed in a magnetic field as indicated in Fig. 17. How should a two-part commutator be attached to the ends of the rectangle, and how should the brushes be placed, to get the best direct E.M.F.

produced at the brushes? Give a curve connecting the value of the E.M.F. with the position of the rectangle.

3. A Gramme ring armature contains 200 turns of wire and rotates at a speed of 1000 revolutions per minute. Its diameter is 2 feet and its axial length 1 foot. Each pole subtends an angle of 120 degrees. The flux density in the air-gap is 5000 lines per sq. cm. Find the P.D. between the brushes.

4. A Gramme ring armature has a simple winding of Z turns, and rotates at n revolutions per minute. There are $2p$ poles, each carrying a flux of N lines. Find the P.D. between the brushes on open circuit.

5. A bipolar drum armature has 1000 wires on its periphery and rotates at 500 revolutions per minute. Find the terminal P.D. if the flux entering the armature from the north pole is one million lines.

6. The armature of a 2-pole 200 volt continuous current dynamo has 400 conductors on its periphery and makes 300 revolutions per minute. Calculate the total flux entering the armature. If the number of turns of wire on each field bobbin is 1200, what is the average value of the E.M.F. induced in these coils if the magnetism dies away in $\frac{1}{10}$ of a second?

7. A bipolar drum armature is built up of 400 core discs, each 0.025 inch thick, the discs being 7 inches external and 2 inches internal diameter. There are 500 armature conductors and the machine is driven at 1000 revolutions per minute. What must be the flux density in the armature in order that the machine may generate 200 volts at no load?

VII.—COMMUTATION, ARMATURE REACTION

1. Draw a diagram of a Gramme armature winding and describe the changes of E.M.F. and current in any one coil during a complete revolution.

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2. Discuss the reasons for shifting the brushes of a dynamo forward as the load increases. Why are carbon brushes employed?

3. Explain why sparking occurs at the brushes of a dynamo when they are not placed in the right position.

4. What do you understand by armature reaction? How does it affect the operation of dynamos and motors?

5. Explain with the aid of diagrams the effect of armature reaction in both dynamos and motors.

6. When the load increases, will the armature of a dynamo with its brushes in the best position tend to strengthen or weaken the magnetic field? Consider also the same question for a motor.

7. Explain why the forward lead of the brushes of a dynamo is usually greater than that corresponding to the magnetic neutral axis. Should the backward lead of motor brushes be greater or less than that corresponding to the field distortion?

8. What kind of lead has to be given to the brushes of a C.C. motor? What are the exact causes that necessitate this particular lead being given to the brushes?

VIII.—CHARACTERISTIC CURVES OF DYNAMOS

1. Sketch and explain briefly the external characteristic curves of a separately excited, a series, a shunt, and a compound dynamo respectively.

2. Given the curve connecting the P.D. and the external current for a shunt dynamo running at a particular speed, the E.M.F. of a battery of storage cells and their resistance, including that of the leads, show how to ascertain graphically the charging current which the dynamo, running at the given speed, will send through the cells.

3. What is the characteristic curve of a dynamo? Show how the characteristic curve of a series dynamo may be used to determine the current that the dynamo will send through a battery of accumulators having a given resistance and E.M.F.

4. Compare the shunt and the series dynamo from the point of view of their suitability for charging accumulators.

5. Can a compound-wound dynamo be safely used for charging cells? Give full reasons for your answer.

6. A series dynamo produces an E.M.F. of 5 volts on open circuit, but on reducing the external resistance the P.D. falls to zero. What is wrong, and how can the fault be rectified?

7. A series dynamo is run at a fixed speed, and the external resistance, which was originally very large, is gradually reduced. Draw a curve showing how the current varies with the external resistance. Consider also the same question with regard to a shunt dynamo.

8. Having given the external characteristic of a series dynamo, draw a curve showing the variation of P.D. with external resistance.

9. You are given the working drawings of a series dynamo and a description of the windings to be put on the armature and field magnets. Show exactly how to *predetermine* the E.M.F. for a given current and speed of rotation.

10. If the curve connecting P.D. and current of a series dynamo is given for a certain speed, how would you construct the similar curve for another speed?

11. Distinguish between series, shunt, and compound dynamos. Show the general nature of the characteristic curves, and compare the relative advantages of each type.

12. A shunt dynamo running at 1300 revolutions per minute is sending a current of 20 amperes through an outside

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circuit. The machine is stopped and then the speed is run up again to 1300 revs. per minute, when it is found that, even on opening the external circuit, the P.D. between the brushes remains quite small. Explain fully the cause of this.

13. A dynamo is level-compounded at 1000 r.p.m.; will it be level-compounded at 750 r.p.m., if the field rheostat remain unaltered?

14. A series dynamo has a P.D. of 100 volts between its terminals when running at 400 r.p.m. and giving 2 kw. What will be the P.D. if the speed be raised to 700 r.p.m. and the output to 3.8 kw.? Total resistance of machine, 1 ohm.

15. Explain all the reasons for the decrease of the terminal P.D. of a shunt dynamo driven at constant speed as the current in the external circuit is increased.

16. Draw curves with abscissæ representing the external resistance, and ordinates representing the terminal P.D., in the case of (a) a series dynamo, (b) a shunt dynamo, (c) a compound dynamo.

17. Two precisely similar series machines are coupled with leads having a known resistance. The current and P.D. curve of the machines at a certain speed is known. If one of the machines is driven as a generator at some other speed, show how to determine graphically the speed at which the other machine will be driven as a motor when a given current flows in the circuit.

18. How is the E.M.F. and the P.D. of a series dynamo connected with the speed, if the current is kept constant?

19. A dynamo is required to give up to 20 kw. at a constant P.D. of 200 volts, at a point $\frac{1}{4}$ mile away. The cable used has a resistance of 0.24 ohm per 1000 yards single. Number of shunt field turns 2000. Find the number of compound coils required, neglecting their resistance. Fig. 18

gives the results obtained from tests on the machine when separately excited.

20. What is the exact function of the series coils in a compound-wound dynamo? Criticise the statement that a compound-wound dynamo is a constant E.M.F. dynamo.

21. Explain fully why a dynamo can be compounded to

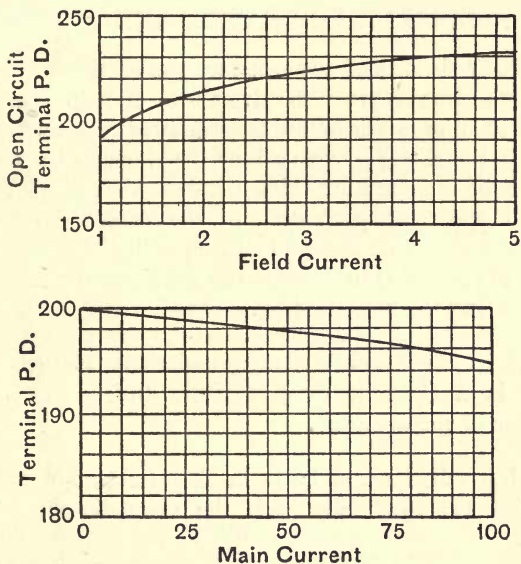


FIG. 18.

produce a constant P.D., but cannot be compounded to produce a constant current.

22. Prove that a series dynamo driven by a steam engine without a governor, but supplied with steam at a fixed pressure in the cylinder, must produce a constant current irrespective of the load.

23. If the speed of an engine used to drive a dynamo charging accumulators slows down considerably, explain exactly

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what will happen, (*a*) if the dynamo be series wound, (*b*) if it be shunt wound.

24. The belt driving a dynamo which is charging accumulators breaks. Explain exactly what happens (1) if the dynamo is shunt wound, (2) if it is series wound.

IX.—LOSSES IN DYNAMOS AND MOTORS

1. The resistance of the armature and of the field winding of a shunt dynamo are respectively 0.15 and 30 ohms, while that of each of a set of 50 accumulators in series is 0.001 ohm. If the E.M.F. developed by the dynamo be 130 volts and that of each cell 2.2 volts, calculate what current will be produced and what proportion of the energy developed by the dynamo will be used, (1) in charging the cells, (2) in heating the cells, (3) in heating the armature of the dynamo, (4) in heating the field winding.

2. Trace the magnetic changes undergone by each particle of iron in a Gramme ring armature during one complete revolution of the armature.

3. How will the iron losses in the armature of a dynamo vary with the speed and with the magnetic flux? Give reasons.

4. What methods are employed to reduce the losses in dynamos and motors due to (*a*) eddy currents, (*b*) hysteresis, (*c*) armature reaction, (*d*) armature copper loss, (*e*) windage?

5. What do you understand by the term "leakage coefficient of a dynamo"? How would you determine it experimentally for any given machine?

6. The power given out by a shunt motor is always less than the mechanical power supplied to it. Enumerate the

various losses and discuss the variation of each loss with variation of load on the motor.

7. What tests would you make on a new dynamo or motor before putting it finally into operation? Describe the construction of the instruments and the methods you would employ to carry out these tests.

8. A 2000 volt E.M.F. 6.7 ampere constant current dynamo has a total resistance of 25 ohms. If the line consists of 8 miles of No. 16 copper wire (resistance 7.7 ohms per 1000 yards), calculate the combined efficiency of the dynamo and line, (a) at full load, (b) at 1000 volts E.M.F.

9. How, and why, do the steady outputs of open, semi-enclosed, and enclosed motors of the same size vary? How does intermittent running affect the rated output of a motor?

10. Show how to obtain the efficiency of a shunt motor quickly and approximately without a dynamometer. Point out the defects of the method and the errors likely to be introduced.

X.—MOTOR CHARACTERISTICS

1. Current is supplied to a motor of resistance m ohms through line wires of resistance l by a generator of resistance g with fixed E.M.F. of E volts. Determine at what speed the motor should run, (a) so that the total power given to the motor shall be a maximum, (b) so that the mechanical power developed by the motor shall be a maximum.

2. Discuss the effect on a shunt motor supplied at constant P.D. of (a) increasing the load without altering the field current and (b) weakening the field current without altering the load.

3. If the speed of the armature of a shunt motor be increased until the E.M.F. it generates exceeds the P.D.

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maintained between the terminals of the machine by the outside mains to which it is connected, explain how the current in the armature and in the field coils will be altered respectively.

4. If constant P.D. be maintained between the terminals of a shunt motor, the speed varies to a small extent with the load. Show how this speed variation is affected by—

- (a) the resistance of the armature,
- (b) the reaction of the armature.

5. In order to keep the speed of a shunt motor exactly constant, it is necessary to weaken the field as the load is increased. Explain fully the reason for this.

6. Why does the speed of a shunt motor usually decrease when resistance is cut out of its field circuit? Under what conditions will it not do so?

7. A bipolar shunt motor has a flux of 5 millions lines per pole. It has 60 conductors on its armature. The armature resistance from brush to brush is 1 ohm. The applied P.D. is 100 volts. Calculate the current taken by the motor and the speed when loaded with a torque of 85 inch-lbs.

8. A 200 volt shunt motor takes 3.6 amperes when running light. To pass 20 amperes through the armature at rest requires a P.D. of 6.6 volts. The field current is one ampere. Find the output and efficiency when the motor current is (a) 20 amperes, (b) 40 amperes.

9. When a shunt machine having its brushes connected with 100 volt mains is driven by an engine at 1000 r.p.m., its armature current falls to zero. If uncoupled from the engine, at what speed will the machine run as a motor when developing 10 H.P. if its armature resistance is 0.05 ohm?

10. A shunt dynamo has a capacity of 150 kw. at 500

volts, and is driven at a speed of 200 r.p.m. The resistance of the armature is 0.05 ohm, and the resistance of the field windings is 200 ohms. If the same machine be run as a motor, calculate its speed when supplied with 150 kw. at 500 volts. The armature reaction may be neglected.

11. Explain what happens when the field circuit of a loaded shunt motor is broken.

12. A shunt motor, the resistance of the armature of which is 0.23 ohm, is connected across supply mains having a P.D. of 106 volts. On turning the armature at 1200 revs. per minute it is found that no current passes through it. Calculate the speed at which it will run when developing 1, 2, and 3 horse-power if armature reaction be neglected.

13. A shunt dynamo has an output of 40 kilowatts at 200 volts and 200 r.p.m. The armature resistance is 0.025 ohm, and field resistance 50 ohms. Calculate its speed as a shunt motor, taking 40 kilowatts at 200 volts.

14. A 10 H.P. shunt motor is run off the 100 volts supply mains. It has an armature resistance of 0.05 ohm and a full-load efficiency of 90 per cent. Find the approximate change of speed from no-load to full-load.

15. A constant P.D. is maintained at the terminals of a series motor. The armature is first held at rest and then allowed to rotate faster and faster. Describe the way in which the current will vary, and the reason for such a variation. What determines the steady value of the current through the motor in such a case?

16. The torque of a standard tramway motor is given by the formula—

$$T = 21.4 \times 10^{-6} \times NC \text{ inch-lbs.},$$

where N is the flux per pole and C the current supplied to the motor. How many conductors are there on the motor armature?

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17. If a 4-pole motor has a series-wound armature with 944 conductors on its periphery, prove that the torque is given by the formula—

Torque = $0.307 \times 10^{-6} \times NC$ metre-kilogrammes,
where N is the flux per pole and C is the current taken by the motor.

18. What are the peculiar characteristics of a series motor which make it suitable for traction purposes? Compare the relative merits of a shunt and a series motor for driving a circular saw through a belt drive.

19. A series motor, employed to raise a definite weight, is joined up to constant pressure mains with a resistance inserted between the motor and one of the mains. Describe exactly what change will be produced in the current, the P.D. between the motor terminals, and the speed when this resistance is diminished.

20. A ventilating fan is driven at 200 revolutions per minute by a series motor taking 10 amperes at 400 volts. If the resistance of the motor is 2 ohms, and the resistance to motion of the air varies as the square of the speed, calculate approximately the P.D. and current required to run the fan at 250 revolutions per minute.

21. Why does a series motor race if the load is thrown off? A small series fan-motor was found not to race to any great extent when the blades were removed. What is the probable cause?

22. A series motor runs on a constant-torque load, and the terminal P.D. is kept constant. What determines the speed at which the motor will run?

23. A series dynamo is run at a given speed, and observations made of the current and P.D. for a number of external resistances. From the curve drawn to represent these results, show how to construct (1) a curve connecting the E.M.F.

and current for that speed, (2) a curve connecting the P.D. and current when the machine is run as a motor at the same speed.

24. If it is desired that the energy of a tramcar when stopping or coasting downhill may not be wasted at the brakes, but be supplied to other cars on the line, consider what type of motor must be used, and also what the driver would have to do when stopping a car.

25. Explain the effect on current and speed of shunting the field coils of a series motor with a resistance equal to that of the field coils, if the torque on the motor is unchanged.

26. Explain fully, with sketches, the use of a tramcar motor as a brake.

27. Describe the methods used for keeping the speeds of electric motors constant under varying loads. Also explain how the speeds of motors working under constant torque are varied in practice.

28. How do the speed and current of (a) a shunt motor, and (b) a series motor, vary with the torque, if the applied P.D. is constant? What advantages has a compound motor over either of the above types?

29. Account fully for the behaviour of a shunt motor at varying loads. How can a motor supplied at constant P.D. be compounded to run at very nearly constant speed at varying loads? Discuss whether armature reaction tends to increase or diminish this constancy of speed.

30. If a compound dynamo be used as a motor without altering the connections, in what way will its speed vary when the load on the motor is varied? Give reasons.

31. If a motor is differentially compounded so as to run at exactly the same speed at all loads, how will its starting torque be affected by trying to start very rapidly?

XI.—MOTOR STARTERS

1. Sketch and describe a motor starter with no voltage and overload releases, suitable for a 5 H.P. motor. What resistance should such a starter have?

2. Calculate the resistances of the various steps and the number of steps for a 5 H.P. 200 volt shunt motor starter, capable of starting under full load. Current not to exceed twice the normal current, and allowed to fall to 1.15 times the normal current. Efficiency 90 per cent., half the losses being armature copper losses.

3. Calculate the resistance of the various steps and the number of steps of a starting resistance for a 20 H.P. series motor for 500 volts. Assume that the motor starts on full load with a current variation between $1\frac{1}{2}$ times and twice the normal full load current. Efficiency of motor, 80 per cent. Resistance of armature and field, 1 ohm. Assume that the flux increases 10 per cent. as the current increases from $1\frac{1}{2}$ to twice its normal value.

4. If you were required to design a starting switch and resistance for a 20 H.P. 400 volt motor as efficiently and yet as cheaply as possible, what further information would you require, and how would it affect the design?

5. Explain how the risk of breaking the field of a shunt machine is avoided in the ordinary motor starting switch.

XII.—ALTERNATING CURRENTS—R.M.S. VALUE—FORM FACTOR

1. Explain what is meant by the root-mean-square value of a variable electromotive force. Find the R.M.S. value of a current which has the following steady values for equal

intervals of time, suddenly jumping from one value to the next ; 0, 1, 2, 3, 2, 1, 0, -1, -2, -3, -2, -1, 0, 1, etc.

2. A rectified sine-wave has a maximum value of 10 amperes. Find the quantity of electricity passing round the circuit per hour.

3. A rectified sine-wave P.D. having a maximum value of 100 volts is applied to a non-inductive resistance of 10 ohms. What will be the readings on a moving coil and a hot wire ammeter respectively, connected in series with the resistance? Why will they differ? Could such a current be used for charging accumulators? If so, which type of ammeter should be used?

4. An alternating P.D. having a maximum value of 570 volts is applied to a non-inductive resistance of 120 ohms. Find the average value of the current that flows and the reading of an electrostatic voltmeter connected across the terminals.

5. A direct current changes in strength every second from 10 to 5 or from 5 to 10 amperes as shown in Fig. 19. Find the steady current which has (a) the same electrolytic effect, (b) the same heating effect.

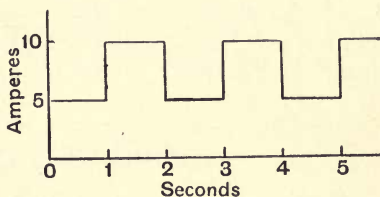


FIG. 19.

6. Explain exactly what is meant by a root-mean-square current of 10 amperes. What is the ratio of the R.M.S. to the mean value of the current, for an alternating current of sine form?

7. A hot wire ammeter and a moving coil ammeter were found to give different readings on a rectified current circuit. What does each instrument measure, and what would be the ratio of their readings, assuming the current to be sinusoidal?

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8. What is meant by the R.M.S. value of an alternating current or voltage? An alternating sine-wave P.D. with a maximum value of 100 volts is applied to a non-inductive resistance of 5 ohms. A hot wire ammeter and a moving coil ammeter are connected in series in the circuit. Find the reading on each.

9. Find the relative heating effect of the two currents shown in Fig. 20.

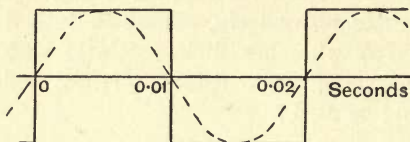


FIG. 20.

10. Find the form factor of the pulsating P.D. obtained between one brush on the commutator and one slip ring of a rotary converter.

11. An alternating current has a maximum value of 10 amperes and follows a sine law. What is the greatest rate of change? Frequency 50 cycles per second.

XIII.—INDUCTANCE

1. What do you understand by the term “coefficient of self-induction of a coil”? How would you determine it experimentally?

2. Define the coefficient of self-induction of a circuit. The coefficient of self-induction of the armature of the Ferranti alternator is practically constant at all loads, while that of the Pyke and Harris inductor alternator varies considerably? Why is this?

3. How do the following resistances to an alternating current differ: (a) a straight wire; (b) a solenoid; (c) a glow

lamp; (d) a water resistance? Why are concentric mains employed for alternating current?

4. A choking coil has a resistance of 10 ohms, but when connected across 100 volt 50 cycle mains, the current taken is only 1 ampere. If the coil has 1000 turns of wire, what flux is produced by a continuous current of 1 ampere?

5. (a) Calculate the approximate self-induction of a solenoid 1 cm. diameter, 1 metre long with 1000 turns of wire.

(b) Find also its resistance if the wire with which it is wound has a diameter of $\frac{1}{2}$ mm.

(c) What P.D. must be applied at any moment if the current is 1 ampere, but is increasing at the rate of 10,000 amperes per second?

6. A wooden toroid or anchor ring has a mean diameter of 6 inches and a circular section of 1 inch diameter. It is uniformly wound with 400 turns of 1 mm. copper wire. Calculate its resistance and inductance. Neglect insulation, and assume $\rho = 0.7 \times 10^{-6}$ ohms per inch cube.

7. How many foot-lbs. of energy are stored in the magnetic field of a coil of 1 henry self-induction when carrying a continuous current of 1 ampere?

8. Explain in your own words why the alternating current passing through a choking coil lags behind the terminal pressure.

9. Explain the effect of self-induction in A.C. circuits, and prove the formula $E = C\sqrt{R^2 + \omega^2 L^2}$ for a circuit containing inductance and resistance in series.

10. If a sine-wave P.D. is applied to the terminals of a choking coil with an iron core, plot out approximately the shape of the current wave, assuming that the saturation of the iron is carried very high.

11. Explain exactly what is meant by saying that the alternating current flowing in a circuit lags behind the E.M.F.

producing it. Find the lag and the maximum value of the current in a circuit of 2 ohms resistance and 0.006 henry self-induction, when a sine-wave P.D. of 100 volts R.M.S. value and 50 cycles per second is applied.

12. An alternating P.D. of 200 volts with a frequency of 50 cycles per second is applied to a coil having a resistance of 1.25 ohms and an inductance of 0.07 henry. Find the value of the current and the cosine of the angle of lag.

13. An alternating current at a frequency of 100 is passed through a non-inductive resistance of 10 ohms and a choker whose resistance and inductance are 1.3 ohms and 0.018 henry respectively. When the P.D. across the whole is at its maximum value of 100 volts, what will be the instantaneous P.D. across the non-inductive resistance?

14. An alternating E.M.F. of 110 volts is applied to an inductive resistance. When the frequency is 80 the current is 15.6 amperes, when the frequency is 40 the current is 19.7 amperes, and when the frequency is 120 the current is 12.1 amperes. Find the value of the resistance, the self-induction and the time constant of the circuit.

15. What must be the self-induction of a choking coil placed in series with a 50 volt 10 ampere lamp, so that the latter may be used on 100 volt 50 cycle mains?

16. A 30 candle-power 80 volt osram lamp takes $\frac{1}{2}$ ampere: what must be the inductance of a choking coil of negligible resistance which will enable the lamp to be used on a 200 volt 50 cycle circuit? Find the angle of lag between the P.D. of the mains and the current. What fraction of a second does this lag represent?

17. An alternating current of 10 amperes is passed through a choking coil with an inductance of 0.01 henry and a negligible resistance, and a non-inductive resistance of 6.28 ohms in

series with the choking coil. The frequency is 100 cycles per second.

Find (a) the reading of a voltmeter across the choking coil,

(b) " " " resistance

(c) " " " whole

(d) the angle by which the current lags behind the P.D. across the whole.

18. A wooden cylinder rotates in a uniform field about an axis perpendicular to the field. This wooden armature carries two coils, one of 100 turns, the other of 50 turns; the two coils are displaced 60° from each other. The strength of field $H = 10$, the area of each coil is 2000 sq. cms., the drum rotates at 1000 r.p.m. Find the reading on a hot wire voltmeter connected across the two coils in series.

19. A circular coil of 1000 turns of wire is rotated with a uniform velocity of 20 revolutions per second about one of its diameters, 50 cms. long, in a uniform magnetic field of strength 1000 C.G.S. units. If the diameter about which the coil rotates is perpendicular to the lines of force, calculate the value in volts and direction of the induced E.M.F. for six positions of the coil 60° apart and also the R.M.S. value of the induced E.M.F.

XIV.—CAPACITY

1. Explain what is meant by a condenser and its capacity. Although the capacity of a condenser made of paraffined paper may be ten times the capacity of a well insulated Leyden jar, show how it may be possible to put a much larger charge on the coatings of the latter than on those of the former.

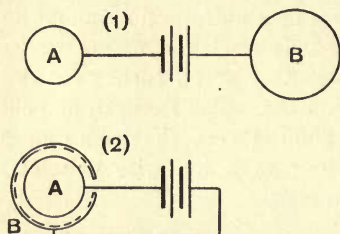
2. What is an electric condenser, how is it constructed in practice, and what are its uses?

3. Explain why a condenser cannot correctly be said to store electricity.

4. How many foot-pounds of energy are stored in a condenser of 20 microfarads charged to a P.D. of 50 volts?

5. Calculate the energy stored in a condenser of 100 microfarads capacity when the P.D. between its terminals is 1000 volts.

6. The insulated spherical conductors A and B (Fig. 21)



are connected with the terminals of a well-insulated battery. State what you know about the potentials of A and B in the two distinct cases (1) and (2).

7. Three similar condensers connected in series have a capacity of 1 micro-

farad. Find the combined capacity when connected in parallel.

FIG. 21.

8. Prove the formula giving the relation between the applied alternating P.D. and the current through a resistance in series with a condenser.

9. A sine-wave P.D. of 100 volts with a frequency of 50 cycles per second is applied to the terminals of a condenser of 30 microfarads capacity. What will be the reading on an A.C. ammeter connected in series with the condenser? What quantity of electricity will pass into the condenser during the time the current is flowing in one direction?

10. Explain in your own words why a condenser takes a leading current.

11. Explain how a condenser shunted by a non-inductive resistance acts like a negative self-induction. Calculate the equivalent inductance of a given capacity and resistance.

12. A 500-volt motor takes 20 amperes at a power-factor

of 0.75. What capacity would have to be employed to increase the power-factor to unity? Frequency 50 cycles per second.

13. What capacity must be placed in parallel with a choking coil of 1 ohm resistance and 0.05 henry self-induction in order to bring the current taken from the mains into phase with the pressure? Frequency = 50.

14. A circuit is made up of an inductive resistance of 7 ohms with a self-induction of 0.04 henry, joined in series with a condenser of 20 microfarads capacity. Find the current in the circuit and the P.D. across the inductive resistance when an alternating P.D. of 200 volts and 50 cycles per second is applied to the circuit.

15. (a) A 15-ampere arc lamp requires a P.D. of 50 volts across its terminals, and has to be connected to 100 volt 50 ~ mains. Calculate the value of the inductance to be placed in series with the lamp and the power-factor of the arrangement, assuming the power-factor of the lamp itself to be unity.

(b) In the above question, how could a condenser be used to bring the current taken from the mains into phase with the P.D.? Calculate the requisite capacity of the condenser.

16. An arc lamp taking 10 amperes at 40 volts is run off 200 volt 50 cycle mains by means of a suitable choking coil. Find the inductance of the choking coil and the P.D. between its terminals. How could you make the load non-inductive, *i.e.* bring the current taken from the mains into phase with the P.D.?

17. A coil having a self-induction of 0.54 henry and a resistance of 6.7 ohms is connected in series with a condenser of 6 microfarads capacity and a P.D. of 70 volts is applied.

(a) Calculate the frequency to give resonance.

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(b) Calculate the current under these conditions.

(c) What will be the percentage variation in current for an increase of 1 per cent. in speed ?

18. Why is Ohm's law apparently not true under certain conditions in an alternating current circuit ? Show how to determine the value of the resulting current when a P.D. of given frequency is applied to a circuit containing resistance, self-induction, and capacity connected in series.

19. Explain the following phenomena observed with the oscillograph :—

(a) Using the Wenstrom machine, which gives a pure sine wave of P.D., the current passing through a choking coil with a saturated iron core was very distorted.

(b) Using the Pyke and Harris alternator, which gives a peaked wave of E.M.F., the current passing through a choking coil without iron core was much less peaky, *i.e.* the irregularities were smoothed out.

(c) On replacing the choking coil in (b) by a condenser, the irregularities in the P.D. wave were highly magnified in the current obtained.

XV.—POWER AND POWER-FACTOR IN A.C. CIRCUITS

1. A coil has a resistance of 10 ohms and an inductance of 0.01 henry. If an alternating P.D. of 100 volts with a frequency of 50 cycles per second is applied to its terminals, find (a) the current, (b) the power taken by the coil, (c) the power-factor.

2. What is meant by the power-factor of an alternating current circuit ? Calculate the power-factor of a circuit of 50 ohms resistance and 0.025 henry inductance, if the frequency is 50 cycles per second.

3. What is meant by the power-factor of a circuit? Calculate the power-factor of a circuit of 20 ohms resistance, and 0.02 henry self-induction. Frequency 50.

4. Explain how the power-factor of an inductive load is improved by connecting a condenser in parallel with the load. What are the advantages of an improved power-factor?

5. If a non-inductive resistance of one ohm be connected to an A.C. supply with a frequency of 100 cycles per second, calculate what amount of self-induction added to the circuit will reduce the current to $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{5}$, respectively, of what it would be with no self-induction. What will be the relative amounts of power given to the circuit in the five cases?

6. How could the power-factor of a circuit be measured, a suitable ammeter, voltmeter, and wattmeter being provided? Give a diagram of the connections.

7. Find the power taken by a coil without iron core, having a resistance of 5 ohms and a self-induction of $\frac{1}{100}$ henry, when an alternating P.D. of 100 volts and 50 $\sim$ is applied to the terminals.

8. Why is it more economical to use a choking coil in series with an arc lamp instead of an ordinary resistance on alternating current circuits?

9. Calculate the mean value of the product of two sine functions of the time having the same frequency but differing in phase; and apply your result to show how a dynamometer may be used to measure the lag between two alternating currents.

10. Prove that, although the alternating current and P.D. may be in phase, the power-factor is not unity unless they have the same wave form. (If you can, prove it generally; if not, take some specific case.)

11. A 10-ampere A.C. arc lamp requires a terminal P.D. of 35 volts at 50 cycles per second. What must be the self-

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induction of a choking coil to enable the lamp to be run on 100 volt mains ?

Could the choking coil be replaced by a condenser ? If so, what should its capacity be ?

What is the amount of energy continually being stored and given out in the above choking coil and also in the condenser ?

XVI.—A.C. GENERATORS

1. Describe with sketches the main features of construction of a large modern alternator for 25 cycles per second at a speed of 300 r.p.m.

2. Explain with sketches the construction of an alternator of (a) copper type, (b) iron type, (c) inductor type. Which type would you advise for use in (a) a railway generating station ; (b) for use with a high-speed engine on an electric lighting circuit with a fairly constant load ; (c) for use in a district where noiselessness is of first consideration ?

3. What is the principle of the inductor alternator ? Give a sketch of a good type of inductor alternator, showing clearly the armature and field coils and the path of the flux.

4. What advantages are possessed by three-phase as compared with single-phase alternators ?

5. Explain how it is that the E.M.F. curve of an alternator with a distributed winding is more nearly a sine wave than the E.M.F. induced in any one of the coils in the armature.

6. The armature of a single-phase alternator is completely covered with a uniformly distributed winding of S turns in series. The R.M.S., E.M.F. induced in one turn is 1 volt. What is the E.M.F. of the whole armature winding ?

7. A D.C. motor armature is tapped at three equidistant

points on the winding and connected to three insulated slip-rings on the shaft. If the P.D. between the brushes on the commutator is 100 volts, what will be the R.M.S. value of the P.D. between two of the slip-rings?

8. Two rectangular coils are arranged so that one can turn within the other, somewhat like the coils of an electro-dynamo-meter. How will the fixed coil be affected if the moving coil is supplied with alternating current at a frequency of 50, and is simultaneously revolved at a speed of 3000 revolutions per minute?

XVII.—TRANSFORMERS

1. Explain briefly with the aid of a simple vector diagram the action of a transformer.

2. Give a vector diagram showing the primary and secondary voltages and currents in a transformer (1) when unloaded, (2) with a non-inductive load, (3) with an inductive load.

3. A 500 kilowatt step-up transformer has 100 turns in the primary winding and 10,000 in the secondary winding. The primary terminal P.D. is 500 volts at 25 cycles per second. The resistances of the two windings are $\frac{1}{500}$ ohm and 20 ohms respectively.

(a) If the maximum flux density is 5000 lines per sq. cm., find the cross-sectional area of the core.

(b) Find secondary terminal P.D. on full load, assuming that all the pressure drop is due to resistance and that the load is non-inductive.

4. Upon what does the ratio of the primary to the secondary P.D. of a transformer depend?

Explain carefully how the relation is affected when the transformer is loaded.

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5. Upon what does the P.D. between the secondary terminals of a transformer depend? How is this P.D. affected by changes of load if the primary voltage is kept constant?

6. Enumerate the various losses of energy in a transformer and state how each loss is dependent upon (a) the load on the transformer, (b) the frequency of supply.

7. Enumerate the various causes leading to—

(a) Losses of power in transformers;

(b) Pressure drop in transformers;

and indicate the means by which these may be reduced to a minimum.

8. Describe the various losses which occur in a transformer. How does each loss affect the working of the transformer?

9. Give a complete account of the method of measuring the power and efficiency of a transformer.

10. Alcohol, instead of mercury, thermometers are sometimes used in testing transformers. Why is this?

11. What tests would you carry out on a transformer before accepting it?

12. What would be the effect of introducing an air-gap of say $\frac{1}{2}$ " in any part of the magnetic circuit of a transformer?

XVIII.—ALTERNATING CURRENT MOTORS

1. Describe the principle and construction of a three-phase induction motor. What are the disadvantages of this type of motor?

2. How many poles has a 3-phase generator running at 250 r.p.m. and giving 50 cycles per second?

What would be the speed of an induction motor having the same number of poles but having 5 per cent. slip at full load?

3. A 6-pole 3-phase induction motor is operated from a supply having a frequency of 25 cycles per second. The slip at full load is 5 per cent., what is the speed of the motor ?

4. Explain with the aid of diagrams how a uniform rotating field is produced in a polyphase induction motor, and show why the motor revolves.

Find the speed of a 3-phase 6-pole induction motor when supplied with current at a frequency of 50 cycles per second, if the slip be 4 per cent.

5. An alternator is coupled to an engine running at 250 r.p.m. The frequency of the alternator P.D. is 50 cycles per second. How many poles has the machine ? At what speed would an 8-pole synchronous motor run when connected to these 50 cycle supply mains ?

6. Show how the rotating field is produced in a polyphase induction motor, and explain why a starting resistance is necessary for large motors of this type.

7. Explain with the help of diagrams the production of a rotating field by means of 3-phase current.

8. Explain how a rotating uniform magnetic field is produced in a 2-phase induction motor. Why are squirrel-cage motors rarely used in large sizes ?

9. Enumerate the various sources of loss of energy in an induction motor.

10. Enumerate the various methods of starting both synchronous and induction motors. What is the relation between speed and torque in the two types ?

11. Enumerate the properties, and state the most suitable applications of synchronous and asynchronous motors respectively.

12. How is it that putting a load on a squirrel-cage

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induction motor causes the current taken by the motor to increase ?

13. Explain exactly how you could reverse the direction of rotation of (1) a 2-phase induction motor ; (2) a 3-phase induction motor.

14. Sketch the speed load curve for a synchronous and an induction motor respectively.

What are the principal characteristics and uses of these two types of A.C. motors ?

XIX.—MISCELLANEOUS A.C. EXERCISES

1. Explain the working of the Duddell oscillograph, showing how a stationary wave is produced and what the wave means. Would the current wave be the same if taken in any part of the same circuit at the same time and under the same conditions ?

2. How would you measure the power given to a transformer by means of an oscillograph ?

3. What are the advantages and disadvantages of alternating currents for practical work as compared with continuous current ?

4. What are the relative advantages and disadvantages of single and 3-phase systems with regard to (*a*) generation, (*b*) transmission, (*c*) distribution ?

5. Explain what is meant by star and delta connection in 3-phase work ? If three 100-ohm resistances are star-connected to a 3-phase supply with 500 volts between the lines, find the current taken.

6. Define "power-factor" and "load-factor," and explain their importance from the point of view of the engineer of an electric generating station.

7. Define the terms “form-factor,” “power-factor,” and “load-factor.” What influences have the latter two factors on the efficient working of a central station ?

8. Under what conditions would you use a choking coil, in preference to a resistance, to steady an arc lamp ?

9. A rotary converter is connected both to D.C. and A.C. mains. What determines to which circuit the converter will deliver energy ?

10. Would you rather use a motor generator or a rotary converter to transform from high pressure A.C. to low pressure D.C. ? Give reasons for your choice.

XX.—THE TRANSMISSION AND DISTRIBUTION OF ELECTRIC POWER

1. (a) Calculate the distance to which 10,000 K.W., at 60,000 volts, can be transmitted over cables 0.1 square inch cross-section, with a line resistance loss of 20 per cent. of the power delivered.

1 mile of 0.2 square inch cable has a resistance of 0.2 ohm.

(b) Calculate the cross-section of the cable to transmit the same power at 2000 volts over the same distance, with the same percentage loss as above.

2. Calculate the diameter of the cable necessary to deliver 1000 K.W. at 30,000 volts P.D., 50 miles away, if 100 K.W. be wasted in line resistance losses.

Resistance of 1 mile of 0.08 square inch cable is 0.55 ohm.

3. It is required to deliver 1000 H.P. at 30,000 volts at a point 60 miles away with an efficiency of 75 per cent. What must be the resistance and cross-section of the line ?

4. What size of copper wire should be employed to

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transmit 10,000 H.P. a distance of 100 miles, (a) at 10,000 volts, (b) at 100,000 volts ?

Assume single-phase transmission with 90 per cent. efficiency.

5. A 50 H.P. 500 volt motor is to be supplied with continuous current from a distributing centre 250 yards away. The efficiency of the motor is 80 per cent. What must be the cross-section of the cable, if the loss in transmission be 3 per cent. of the motor output ? Specific resistance of copper may be taken as 0.66×10^{-6} ohms per inch cube.

6. Find the cost of copper to transmit 15,000 K.W. a distance of 100 miles, allowing 15 per cent. loss in line with voltages of (a) 10,000, (b) 140,000 at the receiving end.

Specific resistance of copper, 0.66 microhm per inch cube. Weight of a cubic inch, 0.32 lb. Cost of copper, £80 per ton.

7. Calculate the distance to which 10,000 K.W. at 60,000 volts can be transmitted and delivered over a cable 0.1 square inch cross-section, having a resistance of 0.44 ohm per mile, with a line resistance loss of 20 per cent. of the power delivered.

8. 400 H.P. has to be transmitted a certain distance. Calculate the relative cost of copper in the following two cases, allowing a loss of 20 per cent. of the original power : (a) Continuous current, 500 volts at receiving end ; (b) alternating current, 2000 volts at receiving end. Efficiency of step-down transformers at receiving end, 90 per cent.

9. Assuming the price of copper to be £80 per ton and the cost of poles, etc., and erection to equal the cost of the copper, consider the advisability of building a generating station 100 miles away from London with coal at 5s. per ton, instead of in London with coal at 15s. per ton.

Maximum output of station = 40,000 K.W.

Pressure of transmission = 60,000 volts.

Annual load factor = $\frac{1}{2}$.

Assume $2\frac{1}{2}$ lbs. of coal per B.O.T. unit.

Allow 10 per cent. for interest and depreciation on line.

Assume 80 per cent. efficiency of transmission.

Specific gravity of copper, 8.9. Specific resistance, 0.66 microhm per inch cube.

10. Tabulate the advantages and disadvantages of using large P.D.s for the transmission of power.

11. If it be decided to treble the power received by glow lamps at the end of a given pair of mains without wasting a greater percentage of the power *en route*, calculate what change must be made in the P.D. between the mains at the transmitting end and in the pressure at which the lamps are intended to run at the receiving end.

12. Compare the relative advantages and disadvantages of continuous and alternating current systems for a large coal mine.

13. What are the advantages and disadvantages of alternate current as compared with continuous current electric distribution? How low may be the frequency supplied to a glow lamp without the eye noticing the periodic changes of current?

14. Explain clearly the advantages of transmitting power at a high voltage. What is the advantage of using alternating current for a high voltage transmission, and what considerations will limit the voltage used?

15. Consider the conditions likely to determine the most economical voltage for a transmission scheme in the colonies.

16. What are the special advantages and disadvantages of large P.D. continuous current systems?

17. Give a brief account of the Thury system of the electric transmission of energy by means of high voltage continuous current.

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What are the practical considerations which limit the distance to which electrical energy can be transmitted ?

18. What would you consider the best type of cable for connecting an electric coal-cutter with the supply mains ? Give reasons.

19. Describe briefly the principle of the 3-wire system of distribution, and discuss its advantages and disadvantages compared with the 2-wire system.

20. What are the advantages of the 3-wire system of distribution ? Describe the several methods employed. Why must a fuse or any other description of cut-out never be placed in the neutral wire ?

21. A dynamo is supplying current for lighting a building half a mile away on the 3-wire system. The cross-section of the two outer wires is 0.3 square inch each, and that of the neutral 0.15 square inch. There are 500 lamps on one side and 300 lamps on the other, each lamp taking 0.3 ampere. What voltage must be maintained at the generator end of the feeder, (*a*) between positive lead and neutral wire, (*b*) between negative lead and neutral wire, in order that the pressure across each lamp may be 200 volts ? (Resistance of an inch cube of copper may be taken to be $\frac{2}{3}$ microhm.)

22. Explain the action of a motor balancer set in a 3-wire station.

23. Is an A.C. 3-wire system possible ? If so, what sort of balancer could be employed ? How could it be regulated ?

XXI.—SECONDARY BATTERIES

1. Why is a secondary battery called an accumulator ? What does it accumulate ? Give approximately the connection between the weight of a secondary battery, the horse-power

which it can steadily develop without injury, and the number of foot-pounds which it can give out.

2. Why are some cells called primary and others secondary? What are their relative advantages and what are the faults to be especially guarded against in secondary cells?

3. Describe briefly the improvements that have been introduced into accumulators during the past eighteen years.

4. What are the industrial uses of accumulators, and which are the properties of an accumulator that are particularly valuable in each case?

5. Show how the resistance of a storage cell may be ascertained at frequent times while it is being charged, and how the energy wasted in charging the cell (apart from that wasted in discharging it) can be measured.

6. Give approximately the numerical results that you would expect to find on testing a good accumulator intended for road traction.

7. A set of accumulators is being charged by means of a series dynamo. Explain fully why the lowering of the speed, even for a very short time, may produce serious damage both to the cells and the dynamo. What sort of result do you think would be obtained if cells were charged with a Thomson-Houston constant current dynamo?

8. State approximately the current that may be taken from a square foot of the positive plate of an accumulator without damage and the energy in foot-pounds that can be safely taken out of one pound weight of positive plate.

9. Describe all the precautions that should be taken in using accumulators in order that they may have a long life.

10. Find the capacity of a battery of 100 cells connected in series, if the capacity of each cell be 300 ampere-hours.

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11. Taking the mean P.D. that has to be maintained between the terminals of an accumulator in charging as 2.1 volts, and the mean P.D. maintained between the terminals in discharging as 1.9 volts, and assuming that the total quantity of electricity that passes through in discharging is 90 per cent. of the quantity that passes through in charging, what is the energy efficiency of the accumulator ?

12. If the E.M.F. of a storage cell on charge and discharge be 2.1 and 1.95 volts respectively, find the difference in foot-pounds in the energy stored and restored when 100 ampere-hours are passed through the cell.

13. Enumerate the various causes of the excessive weight of secondary cells, and discuss the possibility of reducing it.

14. After fully charging a secondary cell to 2.5 volts and letting it stand, the P.D. is found to fall gradually, whereas on standing after discharge to 1.8 volts the P.D. gradually rises. Explain these phenomena.

15. A storage cell contains 15 plates, each plate is 10" square and $\frac{1}{4}$ " from its neighbour. Find the resistance of the electrolyte if 1 inch cube of the solution has 3 ohms resistance.

16. If it is only the spongy lead on the surface of the accumulator plate that takes part in the chemical action, why are accumulator plates always rendered heavy by being made of thick lead ? Why is it that a depth of 3 inches is always left between the bottom of the plates and the bottom of the cells ?

17. Explain why the discharge of an accumulator should be stopped when the P.D. drops to a certain value.

18. Draw the normal curves of charge and discharge of an accumulator with constant current, and explain in detail the reason for their particular shapes.

19. A cell which cannot be detached from a battery of accumulators wants charging for a longer time than the other cells. Describe with sketches how you would do this.

20. A battery of accumulators is being charged. What indications would serve to show when the cells are fully charged, and what signs would lead you to suspect that any individual cell was out of order? What steps would you take to discover the fault and remedy it?

21. A battery consists of 55 storage cells in series, each cell has a resistance of 0.001 ohm, an E.M.F. of 2.05 volts, and contains 10 + and 11 - plates $12'' \times 12''$. If 0.04 ampere be taken from the cells per square inch of positive plate surface, what will be the P.D. at the distributing board at full load current, if the leads to the board have a resistance of 0.017 ohm?

22. Give a simple explanation of the chemical actions involved in charging and discharging an accumulator.

Explain the changes which occur in the specific gravity of the electrolyte.

23. Explain the chemical action of the secondary cell during charging and discharging. Why should the cell never be discharged below 1.8 volts?

24. Explain why the density of the acid serves as an indication of the state of charge of an accumulator.

25. A storage cell is being charged with a current of 36 amperes. Find the weight of sulphuric acid liberated per hour due to the chemical action taking place, having given that 1 coulomb of electricity deposits 0.00107 gramme of lead. Find also the weight of lead peroxide formed in the same time.

26. If the capacity of a cell for central station use is about $2\frac{1}{2}$ ampere-hours per pound of cell, what percentage of the total weight of the cell enters into the chemical reactions?

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27. Why has accumulator traction not proved satisfactory up to the present ?

28. How far will a battery weighing 10 cwt. propel a cab weighing $1\frac{1}{2}$ tons (including battery and motor) ? The output of the battery is 10 watt-hours per pound weight. Resistance to traction is 30 pounds per ton. Efficiency of motor and gearing 75 per cent.

29. A tramcar weighing 6 tons without battery is to be propelled at 10 m.p.h. If the power given by the cells is 7 watts per pound and the necessary tractive force 15 pounds per ton, find the weight of cells required. Efficiency of motor 85 per cent.

30. What are the advantages and disadvantages of accumulators for electric traction ?

A car is fitted with accumulators and a motor which has to develop $1\frac{1}{2}$ H.P. for 4 hours. What must be about the least weight of the motor and of the accumulators so that they will stand this discharge without damage ? Also about how much energy must be used in replacing the energy taken out in the discharge ?

31. When accumulators are charged by a dynamo driven by a gas engine, the engine can be started by means of the accumulators, the dynamo automatically changing from a motor into a dynamo when the gas engine gets up speed. Give sketches showing this arrangement in detail.

32. What are the advantages of accumulators in an electric generating station ? Sketch the arrangement of a good battery switch to enable the battery to be charged from a dynamo and at the same time be connected to the supply mains.

33. Explain how a storage battery is utilised in a central station to keep the load on the generators constant. What is the function of a booster in such a station ?

34. What advantages and disadvantages are introduced by having a battery in a tramway generating station ?

35. Compare the advantages and disadvantages of an accumulator battery as compared with spare generators, (*a*) in a lighting station, (*b*) in a traction station.

36. Describe the action of a battery as commonly used in a traction station. Explain the effect of adding an automatic reversible booster.

37. What is the function of a booster in a central station ?

A reversible booster is used in conjunction with a 200 volt battery having a discharge capacity of 200 amperes. The charging current until the P.D. of each cell rises to 2·3 volts is 100 amperes and from 2·3 volts to the end of charge is 50 amperes. Find the K.W. capacities of the booster and booster-motor respectively.

XXII.—ELECTRIC TRACTION

1. If the tractive resistance of a car on the level be 30 pounds per ton, find the gradient down which the car will coast at a uniform speed.

2. Find the relation between the tractive resistance in pounds per ton and the energy consumption in watt-hours per ton mile.

How many watt-hours per ton-mile must be added for a 1 per cent. gradient ?

3. What are the factors which determine the mechanical pull required to draw a car along a line ? A tramcar is equipped with 2 motors and is running on a line up an incline of 1 in 30. The weight of the car is 12 tons and the resistance to traction 25 pounds per ton. If the motors are exerting 10 H.P. each, find the speed of the car in miles per hour.

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4. Weight of locomotive = 40 tons.

Weight of train (without locomotive) = 250 tons.

Tractive resistance = 12 pounds per ton.

What is the maximum acceleration possible on the level, and what time is required to reach a speed of 60 miles per hour, if the rails are clean but wet and give an adhesive force on the wheel of 15 per cent. of the dead weight? Assume total weight of locomotive on driving wheels.

5. A tramcar weighing, when loaded, 12 tons has motors which give a torque of 5000 pound-feet on the wheels while starting. The tractive effort required to overcome friction is 20 pounds per ton. Diameter of wheel 30 inches. Find the time taken to bring the car from rest up to a speed of 15 miles per hour.

6. A train of 50 coal trucks each weighing 15 cwt. is being hauled up an incline of 1 in 20 at the rate of 2 miles per hour. The tractive force required on the level is 50 pounds per ton. What current will be taken by the 200 volt haulage motor, the efficiency of which, inclusive of gearing, may be taken as 60 per cent.?

7. The resistance to traction of a tramcar on the level is 15 pounds per ton. The highest speed attainable by a 10-ton car up an incline of 1 in 40 is 8 miles per hour. Find the current taken in this case from the 500 volt trolley wire, if the combined efficiency of motor and gearing be 75 per cent.

8. An electric train, weighing 100 tons, is standing on an incline of 1 in 40. The tractive force is 15 pounds per ton on the level. The train starts up the slope with a uniformly increasing speed, attaining the full speed of 25 miles per hour in 15 seconds. The gear ratio is 4.8, the wheels are 33" diameter, the efficiency of the gearing is 80 per cent., and there are four motors. What torque must be exerted by each motor during the start?

9. What weight of cells would be necessary to make a 50

mile run with a driver and 4 passengers in a carriage weighing 1 ton without passengers or cells? Assume a level road, tractive force 20 pounds per ton : 1 pound of cells gives 8 to 12 watt-hours.

10. An electric automobile weighs 2 tons gross, 15 cwt. of which is due to the cells. If the cells have a capacity of 10 watt-hours per pound weight, and the efficiency of the motor and gearing be 70 per cent., what distance would it be possible to run on a single charge, if the tractive force on the level be 50 pounds per ton and the average gradient a rise of 1 in 200?

11. Tabulate the advantages and disadvantages of the trolley system, conduit system, and surface-contact system of electric traction for street tramways.

12. How can the series motors of a tramcar be used as brakes? Give a diagram showing the alteration of connections from running to braking position.

13. What is the principle and object of series-parallel control of traction motors? Explain the various steps by which a tramcar with two motors is gradually started and brought up to full speed.

14. What are the advantages of series parallel control in traction work? Give a sketch showing the connections of the reversing barrel of a tramcar controller.

15. In what proportion is the energy wasted in starting resistance reduced by the use of two motors and series-parallel control? What further reduction could be effected by the employment of 4 motors?

16. What is the principle and action of the magnetic blow-out in a tramcar controller? Give a sketch showing the arrangement of the magnet coil and the path of the flux in a modern controller.

XXIII.—PHOTOMETRY. GLOW LAMPS.

1. State the principles upon which the measurement of the intensity of a source of light depends. Describe a reliable form of photometer and the method of using it to obtain the candle-power of a glow lamp.

2. If the barometer varies over a range of 3 inches and the humidity of the air varies from 2 to 20 litres per cubic metre, find the greatest possible difference in the candle-power of a 16 c.p. glow lamp as determined by means of a Pentane lamp on two different occasions. Tests made at the National Physical Laboratory showed that the candle-power of a 10 c.p. Pentane lamp was given by the formula

$$\text{C.P.} = 10 - 0.008(760 - b) + 0.066(10 - h)$$

where b = height of barometer in mm. and h = humidity in litres of water vapour per cubic metre of dry air.

3. Give a brief account of the method of manufacture of modern carbon filament glow lamps. How are the dimensions of the filament for a given candle-power influenced by the voltage for which the lamp is designed?

4. Why do incandescent lamps use a greater number of watts per candle than arc lamps? What are the considerations that enable you to settle the proper P.D. to maintain at the terminals of an incandescent lamp? Consider whether incandescent lamps when supplied with alternate current should have a greater or less pressure maintained between the terminals than when supplied with continuous current.

5. Glow lamps are purchased for running at 100 volts. Consider what will be the advantages and disadvantages of running them at a steady pressure of, (a) 97 volts instead of 100, (b) 103 volts instead of 100. Give examples when it would be profitable to adopt (a) and when to adopt (b).

6. Why are metallic filament lamps of small candle-power only made for low voltages? How is this disadvantage overcome in the use of the lamps on high voltage systems?

7. Why is a ballast resistance necessary in the Nernst lamp? Explain the peculiar type of resistance employed.

8. The ballast resistances of Nernst lamps are contained in bulbs filled with hydrogen because the hydrogen cools the filament much better than would a vacuum. Explain the meaning of this statement in face of the fact that the iron wire has to be raised to a red heat to make it effective.

9. What are the points to be considered in ascertaining the best P.D. to be maintained between the terminals of a particular type of glow lamp? What are the advantages and disadvantages of changing over the supply of electric energy in a district from 100 volts to 200 volts?

10. A tantalum lamp for 110 volts has a filament 650 mm. long and $\frac{1}{20}$ mm. diameter. The specific resistance of tantalum when running is 83 microhms per cm. cube. The efficiency is $1\frac{3}{4}$ watts per candle. What is the candle-power of the lamp?

11. The B.O.T. limits the variation of P.D. on a consumer's terminals to 4 per cent. above or below the declared pressure. To what variation of candle-power does this correspond: (a) for a carbon lamp, and (b) a metal filament lamp, the index for the relation between C.P. and P.D. being 6.5 and 4 respectively?

12. If the C.P. of a glow lamp varies as the cube of the watts and also as the seventh power of the voltage, find the efficiency of a lamp at 90 volts which at 100 volts gave 16 c.p. for $\frac{2}{3}$ ampere.

13. Write down in symbols or figures the approximate equations connecting—

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(a) Candle-power and potential difference ;

(b) „ and current

for electric glow lamps under normal conditions of use. Compare the ratios of the corresponding constants in (a) and (b) for carbon filament and metallic filament lamps respectively, of equal candle-power and voltage. Explain the differences, if any, in these ratios for the two kinds of lamps.

14. If the candle power of a carbon filament glow lamp varies as V^7 and also as C^3 , find the relation between current and resistance.

15. Draw curves showing approximately the relation between (a) C.P. and P.D., (b) C.P. and current, (c) C.P. and watts per C.P. in a 16 C.P. 200 volt carbon filament glow lamp.

16. If carbon glow lamps costing 1s. each produce 16 candles when run at 3 watts per candle and last 500 hours, while they produce 13 candles and last 1000 hours, when run at 4 watts per candle, calculate which is the more economical number of watts per candle to employ when a B.O.T. unit costs 5d.

17. If the wholesale price of a good modern glow lamp be taken at 2s., calculate at about what price it would be necessary to be able to obtain a B.O.T. unit so that light for light electricity could compete with gas.

Take gas at 2s. 10d. per 1000 cubic feet, and inverted burners giving 10 candle-hours per cubic foot. Assume consumption of 1.3 watts per candle for electric lamp. Cost of mantle, 4d. ; life of mantle, 300 hours. Life of electric lamp, 1200 hours. Assume 50 c.p. lamps.

18. If a new 16 c.p. carbon lamp cost 1s. and take 60 watts, find when it must be replaced in order to get the minimum total cost per candle-hour under the following conditions :—

Cost of energy, 4d. per unit. Watts taken by lamp

constant during whole life, but C.P. decreases uniformly, reaching 8 c.p. after 1000 hours.

19. What life must a 16 c.p. metallic filament lamp have to make it as efficient as regards total cost per candle-hour as the ordinary carbon filament lamp, assuming the former takes $1\frac{1}{2}$ watts per candle-power and costs 2s. 9d., while the latter takes 4 watts per candle-power, costs 9d., and is renewed every 1000 hours? Neglect decrease of C.P. during life. Energy 4d. per unit.

20. If a Welsbach burner gives an average of 6 candle-hours per cubic foot of gas, if a mantle lasts 300 hours and costs 5d., and the price of gas is 2s. 10d. per 1000 cubic feet, calculate at what price a B.O.T. unit must be sold so that using 20 watt 16 c.p. lamps lasting 600 hours and costing 2s. 6d. each may be as economical as employing Welsbach burners. Assume 40 c.p. for the gas burner.

21. The following are the results obtained on testing carbon glow lamps run at 100 volts—

Time in Hours.		C.P. per Lamp.		Current in Amperes.
0	...	16	...	0·62
100	...	18	...	0·65
250	...	16	...	0·64
500	...	15	...	0·68
750	...	14	...	0·70
1000	...	12	...	0·70

The price of a B.O.T. unit is $3\frac{1}{2}$ d., price of a new lamp is 9d., and the lamps are renewed every 800 hours. Calculate the average cost of 100 candle-hours. In this case which will diminish the cost of lighting the more, a 20 per cent. reduction in the price of a lamp or in the cost of a B.O.T. unit?

XXIV.—ARC LAMPS

1. What do you understand by the candle-power of (a) a glow lamp, (b) an arc lamp? How would you determine the candle-power in each case?

66 EXERCISES IN ELECTRICAL ENGINEERING

2. Why is it necessary to place a resistance in series with an arc lamp? Under what circumstances could the resistance be replaced by a choking coil?

3. An arc lamp using solid carbons 5 mm. apart and taking 10 amperes is to be run off a 100 volt circuit. What resistance will it be necessary to insert in series with the arc and how many watts will be spent in the resistance? What proportion of the whole power is used in the arc? (See Fig. 22.*)

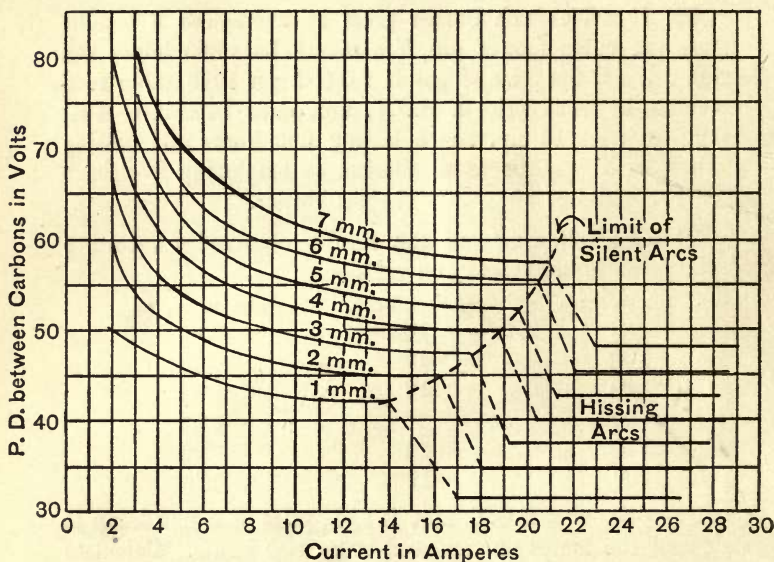


FIG. 22.—P.D. and current for different lengths of arc. Solid carbon + 11 mm., - 9 mm. diameter.

4. An arc is maintained between solid carbons of 11 and 9 mm. diameter. The supply P.D. is 70 volts and the resistance in series with the arc is $1\frac{1}{2}$ ohms. What are the limits between

* Fig. 22 is reproduced from Mrs. Ayrton's book "The Electric Arc," by the kind permission of the authoress and publishers.

which the length of the arc can be varied and what are the greatest and smallest currents? (See Fig. 22.)

5. How does the P.D. between the carbons of a direct current open arc change when the carbons are slowly separated and the outside resistance slowly varied so as to keep the current constant? How does the current vary when the carbons are slowly separated and the outside resistance slowly varied so as to keep the P.D. constant? Explain the cause of the results obtained.

6. Mrs. Ayrton found that for solid carbons the power expended in the arc was a linear function of the current when the length was kept constant, and also a linear function of the length when the current was kept constant.

Prove from these facts that the P.D. across the arc is represented by the following formula—

$$V = a + bl + \frac{f + gl}{C}$$

where a , b , f , and g are constants.

7. Draw a polar curve showing approximately the distribution in a vertical plane of the light given out by an arc lamp of the open type. Show also a construction by which the mean spherical candle-power of such a source can be determined. Give proof.

8. If the polar curve of an arc be rotated about a vertical axis, it will describe a solid of revolution. It has been suggested that the radius of a sphere of equal volume would be the mean spherical candle-power. Investigate this.

9. Tests on a flame arc with downward feeding carbons, gave the following C.P. in different directions—

Angles to the horizontal }	0°, 10°, 20°, 30°, 40°, 50°, 60°, 70°, 80°, 90°
C.P. (Hefner)	900, 1300, 1500, 1800, 2300, 2900, 3300, 3380, 3460, 3550

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Draw the polar curve.

A hall 100 feet long, 60 feet wide, and 40 feet high, is illuminated by the above lamp suspended at the centre 5 feet below the ceiling. Compare the illumination of the floor at the centre with that of the floor in a corner of the room. Neglect reflection from walls and ceiling, etc.

10. Find the approximate mean spherical candle-power and the mean hemispherical candle-power of the lamp in the foregoing question.

11. How is the distribution of the light from an arc lamp affected by an opaline globe put round it? How would you proceed to determine the absorption of the globe? Would you obtain the same results from tests made on a piece of the same glass 3" square?

12. Under what circumstances can simple shunt or simple series arc lamps be used? Why are differential lamps essential in other cases? Describe with sketches the mechanism of any arc lamp with which you are acquainted.

13. In alternating current arcs themselves, not including the mechanism, the watts are less than the product of amperes and volts. How do you account for this?

ANSWERS TO NUMERICAL QUESTIONS

I

1. 1120 grammes. 2. 18,000 coulombs. 5. 1 B.O.T. = 3415 B.Th.U. 6. $0.3d$. 7. $\frac{1}{2}d$. 8. 11.6%. 9. 22.7%. 10. (a) 1 H.P.-hour = 640,000 cal; (b) 6 to 12 lbs. 12. 1 unit = 1.34 H.P.-hours = 2,650,000 ft.-lbs. 13. £53. 14. $17d$. 15. 85 H.P., $4.7d$. 16. 33.6%. 17. (a) 9.7 H.P.; (b) $0.07d$. 18. 18.1 H.P., $\frac{1}{4}d$. 19. $0.47d$. 21. 1.72 microhms. 22. 94 microhms per cm. cube. 23. 0.485. 24. 10. 25. $3\frac{1}{3}$. 26. 103.6, 102.6, 102.1. 28. 10. 29. Power 3 : 4. Energy 3 : 2. 30. (a) $R_c = R_j + R_l$; (b) $R_c = 3(R_j + R_l)$. 31. 50°C . 33. 40.6 ft., 0.123 inch.

II

1. 0. 2. 187.5. 10. 0.222. 12. 12.35. 13. 8.3. 14. 69. 15. 15,100. 16. 304. 17. 6 amps. 18. 1000. 19. 1430. 20. 5025, 0.023, 21,800. 21. 8950. 22. 30.3 lbs. 23. 34,030. 28. 35.7. 31. 23,450 ergs. 33. 1.7 amps. 34. 164.5. 35. (a) 3320; (b) 1790 lbs.

III

1. 0.0432 lb. 2. 0.09 lb. 3. 18 dyne-cms. 4. 1870 inch-lbs. 12. 42.5 microcoulombs. 13. 10^{-4} coulombs. 15. 1600. 16. 0, 0.0111, 0.0128. 17. 300. 18. 122. 19. 1.25.

V

1. 0.929.

VI

3. 325 volts. 5. $83\frac{1}{2}$ volts. 6. 10^7 ; 1200 volts, each. 7. 7450.

VIII

14. 190 volts. 19. 40.

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IX

1. 97.1 amps., 81.5 %, 3.6 %, 11.6 %, 3.3 %. 8. (a) 55 %; (b) 10.5 %.

X

7. 20 amps., 1600 r.p.m. 8. (a) 4.2 H.P., 79 %; (b) 9 H.P., 84.7 %. 9. 960 r.p.m. 10. 188.5 r.p.m. 12. 1180, 1160, 1140 r.p.m. 13. 190 r.p.m. 14. 4 %. 16. 760.

XI*

2. 5 steps, $1.8 + 1.15 + 0.7 + 0.45 + 0.3 = 4.4$ ohms.
3. 4 steps, $1.95 + 1.5 + 1.25 + 1.0 = 5.7$ ohms.

XII

1. 1.78. 2. 22,900 coulombs. 3. 6.36, 7.07. 4. 3.02 amps, 403 volts. 5. (a) 7.5; (b) 7.9. 6. 1.11. 8. 14.15, 12.73. 9. 2:1. 10. 1.225. 11. 3142 amps. per sec.

XIII

4. 31,450. 5. (a) 10^{-4} henry; (b) 2.72 ohms; (c) 3.72 volts. 6. 0.73 ohm, 0.21 millihenry. 7. 0.37. 11. 43.5° , 51.2 amps. 12. 9.01 amps., 0.0566. 13. 44.2 volts. 14. 4.95 ohms, 0.01 henry, 0.002. 15. 0.0276 henry. 16. 1.165, 66° , 0.00367. 17. (a) 62.8; (b) 62.8; (c) 89; (d) 45° . 18. 1.96 volts. 19. 1230 volts.

XIV

4. 0.0185. 5. 50 joules. 7. 9 mfd. 9. 0.944, 0.0085 coulomb. 12. 84.2 mfd. 13. 199 mfd. 14. 1.37 amps., 19.8 volts. 15. (a) 0.0184 henry, 0.5; (b) 414 mfd. 16. 0.0624 henry, 196 volts. 17. (a) 88.6; (b) 10.45 amps.; (c) 26.5 %.

XV

1. (a) 9.54; (b) 910; (c) 0.954. 2. 0.987. 3. 0.955. 5. 2.76, 4.5, 16.17, 7.8 millihenries, $1, \frac{1}{4}, \frac{1}{9}, \frac{1}{16}, \frac{1}{25}$. 7. 1429 watts. 11. (a) 29.8 millihenries; (b) 340 mfd.; (c) 2.98 joules.

XVI

6. $\frac{2S}{\pi}$. 7. 61.25.

XVII

3. (a) 900 sq. cms.; (b) 49,600 volts.

* These questions admit of a certain amount of latitude.

ANSWERS TO NUMERICAL QUESTIONS. 71

XVIII

2. 24, 237·5. 3. 475. 4. 960. 5. 24, 750.

XIX

5. 2·89.

XX*

1. (a) 90 miles; (b) 90 sq. inches. 2. $\frac{1}{4}$ ". 3. 402 ohms, 0·0126 sq. inch. 4. (a) 5·9; (b) 0·059 sq. inch. 5. 0·108 sq. inch. 6. (a) £1,040,000; (b) £5,300. 7. 82 miles. 8. 1 : 14·4. 11. $\sqrt{3}$ times. 21. (a) 219; (b) 197·9.

XXI

10. 300 amp.-hours. 11. 81·4%. 12. 39,800 ft.-lbs. 15. 0·000536. 21. 104·45. 25. 132, 160·5 grammes. 26. 6 %. 28. 94 miles. 29. 308 lbs. 37. 12 K.W., 4·5 K.W.

XXII

1. 1 in 75. 2. (a) lbs. per ton = watt-hours per ton-mile $\times 0·503$; (b) 44·8. 3. 6·25 m.p.h. 4. 0·5 ft. per sec. per sec., 3 minutes. 5. 4·88 secs. 6. 200 amps. 7. 30·1 amps. 8. 2160 lb.-feet. 9. 374 lbs. 10. 48 miles. 15. 50 %, a further 12·5 %.

XXIII

2. 14·4 to 17·3. 10. 25 c.p. 11. Carbon, + 29 %, - 23 %. Metal, + 17 %, - 15 %. 12. 6·8 watts per c.p. 17. $2\frac{1}{2}d$. 18. 400 hours. 19. 200 hours. 20. 2·36 pence. 21. 1·57 pence.

XXIV

3. 4·49 ohms, 449 watts, 55·1 %. 4. 2·2 to 5·4 mm., 7·5 to 16·5 amperes. 9. 14·1 : 1. 10. 1060, 2050.

* Unless otherwise stated, the voltages and powers in the exercises in Section XX. are those at the consumers' end of the line.

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